Phosphorus Management: Questions of Balance

Dr. Don Flaten, Professor
Dept. of Soil Science, Univ. of Manitoba

Saskatchewan Soils and Crops Workshop
March 7, 2018

University of Manitoba

P Balance Issues

1. Short term vs. long term P management strategies
2. Crop production vs. environmental protection
3. Environmental challenges for P vs. other environmental challenges

UNIVERSITY OF MANITOBA

Why is phosphorus balance important?

Food - P is a unique element that is essential for almost all life

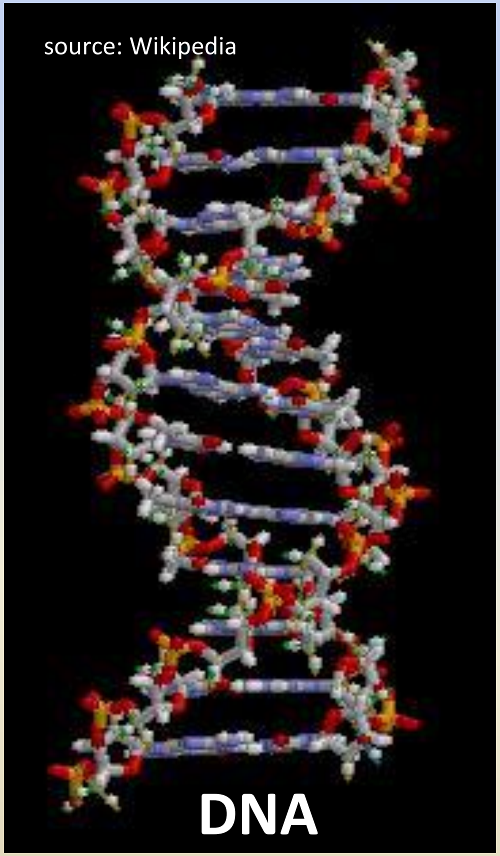
Source: Christiansen/
Scientific American

Water - small amounts of excess P cause big problems with water quality

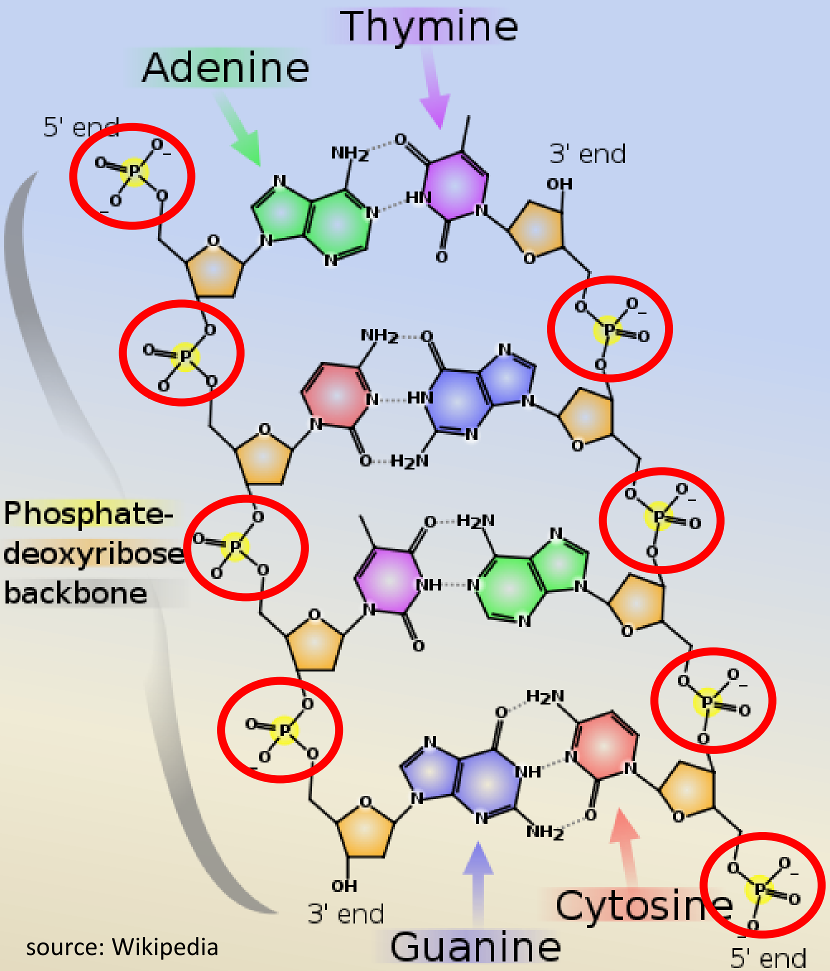
Photo: MB Conservation

University of Manitoba

Examples of molecules that are vital for life and that require P



genetic coding & control



source: Wikipedia

University of Manitoba

P Management in Corn & Soybeans in Manitoba

University of Manitoba

Corn Production in Manitoba

- Grain corn acres & yields are increasing in MB
- Short growing season and cold soils at planting
- Often planted on land with canola in rotation
- Conservation tillage an important BMP

UNIVERSITY OF MANITOBA

Corn Rotation Study: Starter P & Zn

Fertilization strategies for corn grown after canola (non-mycorrhizal) vs. soybean

P?

Zn?

University of Manitoba

Corn Rotation Study Treatments

Crop Treatments - Canola or Soybeans

Fertilizer Treatments (sidebanded 2” by 1” at planting)

Control

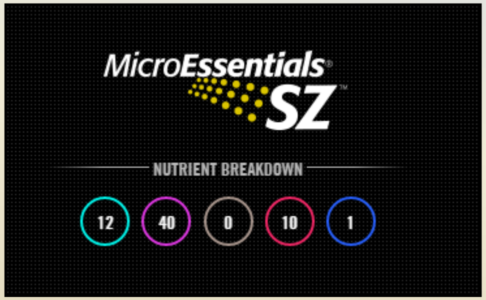
1. No P Check

MAP (11-52-0) + AS (21-0-0-24)

2. 27 P_2O_5 0 Zn 6.8 S lbs/ac
3. 54 P_2O_5 0 Zn 13.5 S lbs/ac

MicroEssentials SZ (12-40-0-10S-1Zn)

4. 27 P_2O_5 0.68 Zn 6.8 S lbs/ac
5. 54 P_2O_5 1.35 Zn 13.5 S lbs/ac



MicroEssentials (December 14, 2015) http://www.microessentials.com/#fusion-process

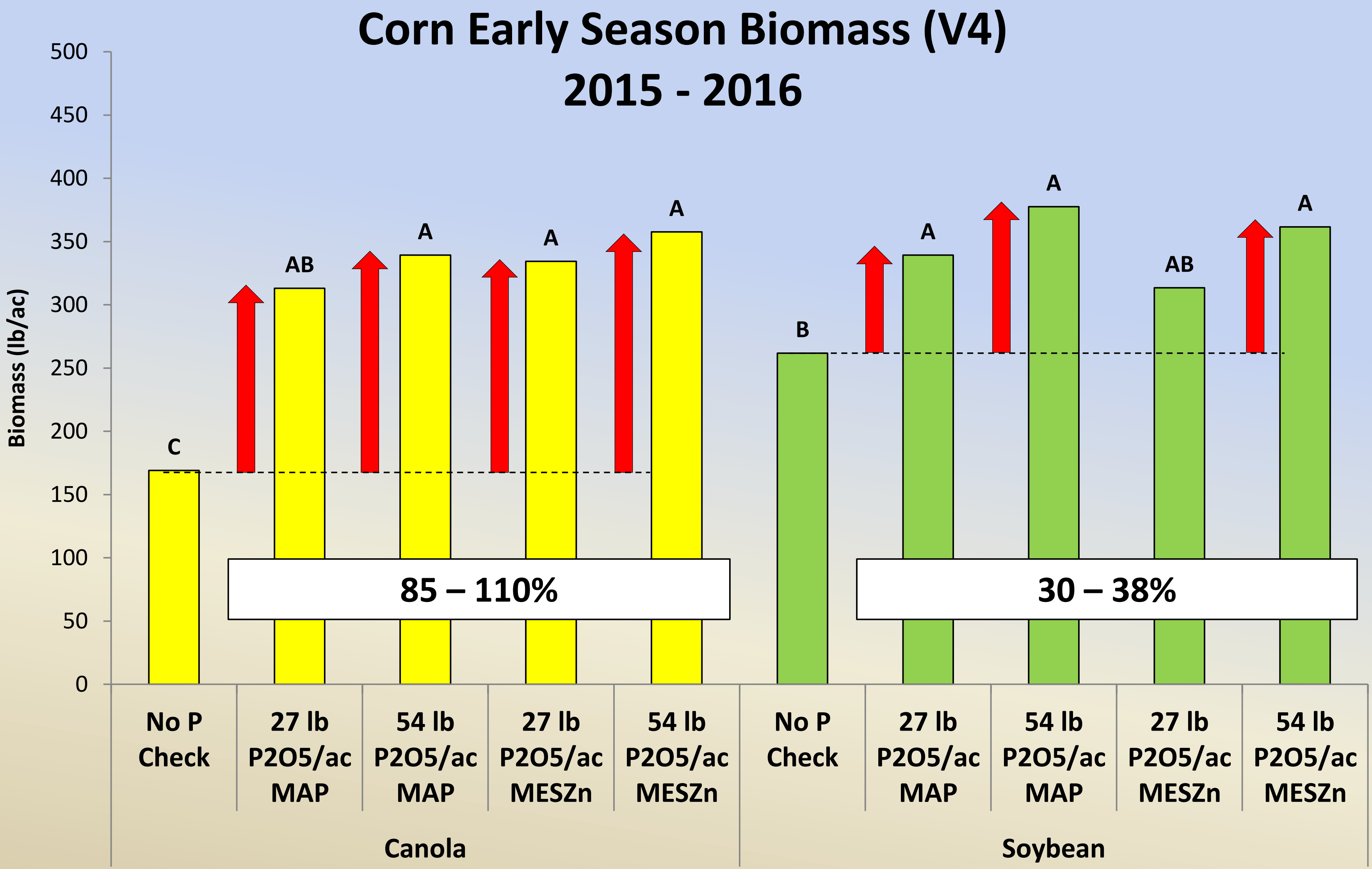
University of Manitoba

Corn Rotation Study:
Early Season Response to Starter

MAP 27 lb P_2O_5/ac   No P Check   P deficiency symptoms at V3

UNIVERSITY OF MANITOBA

Corn Rotation Study



University of Manitoba

Corn Rotation Study

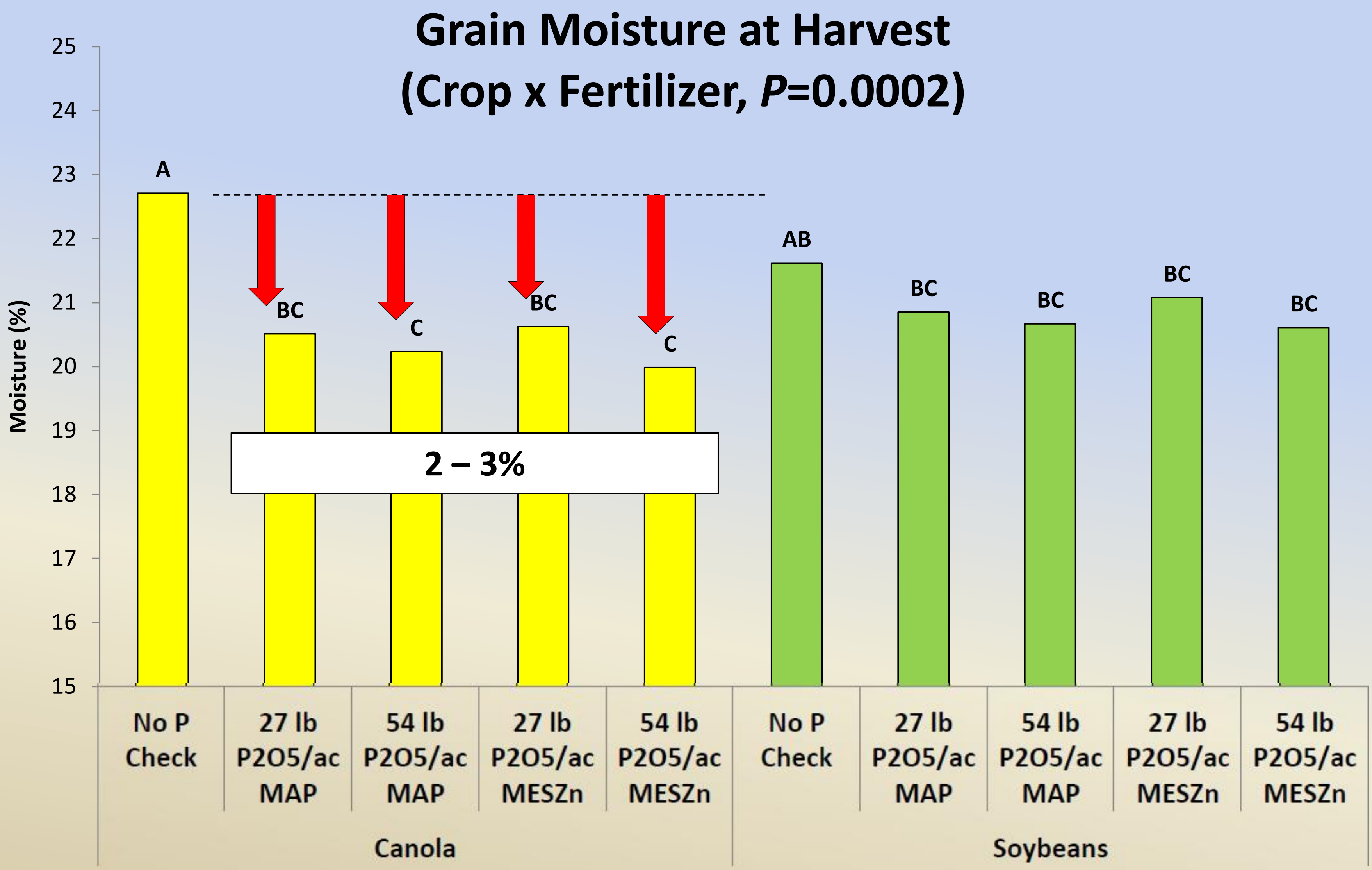
Silking differences as compared to control plots

Site-year	Maturity Advance (days)	Fertilizer and Crop
Carman 2015	+2 to 3	All fertilizer treatments, corn on canola
Stephenfield 2015	ns	ns
Carman 2016	+2 to 7	All fertilizer treatments, regardless of crop

Earlier tasseling and taller corn plants with spring side-banded 27 lb P_2O_5/ac as MAP (L) and 27 lb P_2O_5/ac as MESZn (R) vs. control (M) at Carman following canola stubble

UNIVERSITY OF MANITOBA

Corn Rotation Study

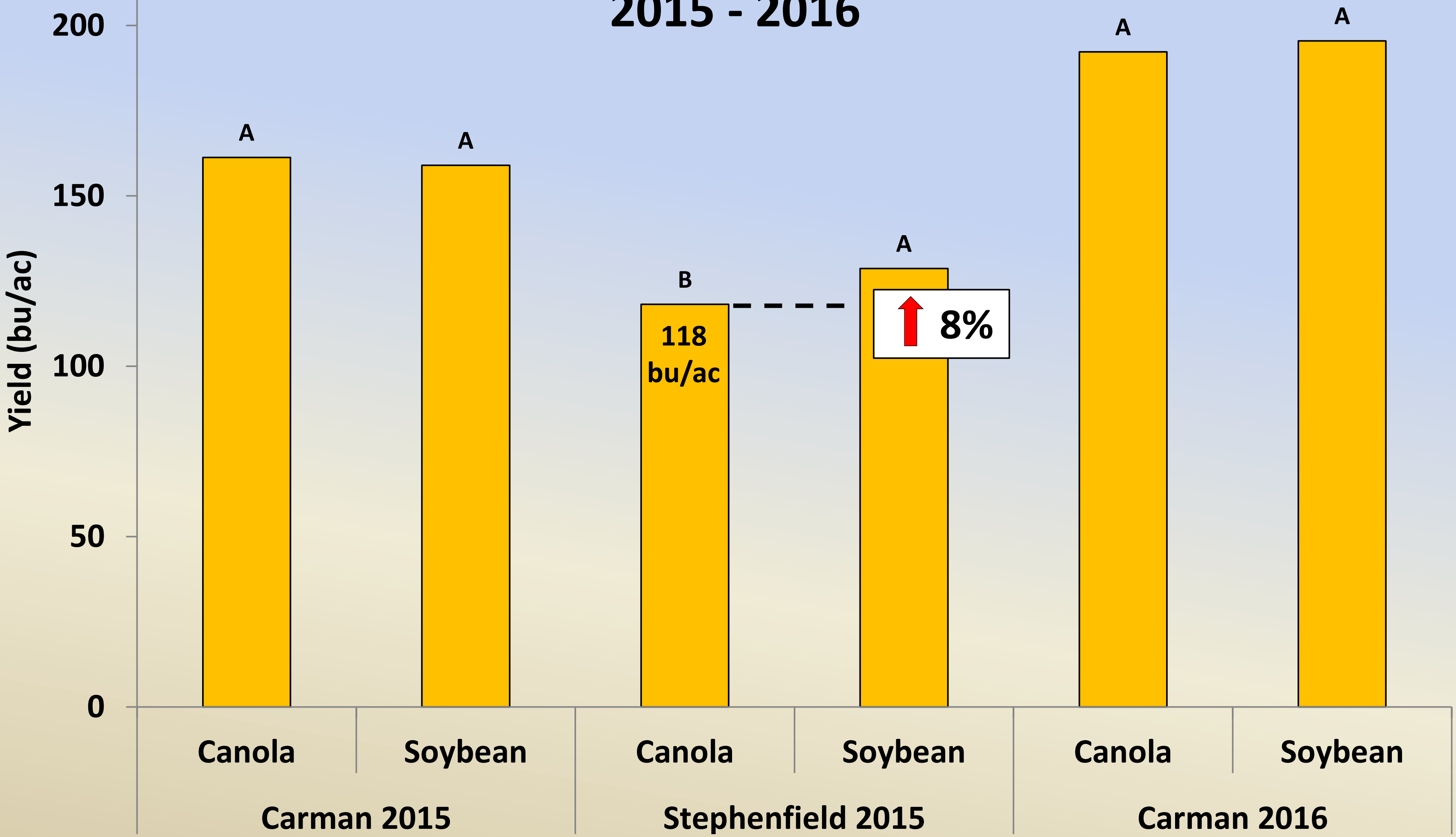


UNIVERSITY OF MANITOBA

Corn Rotation Study

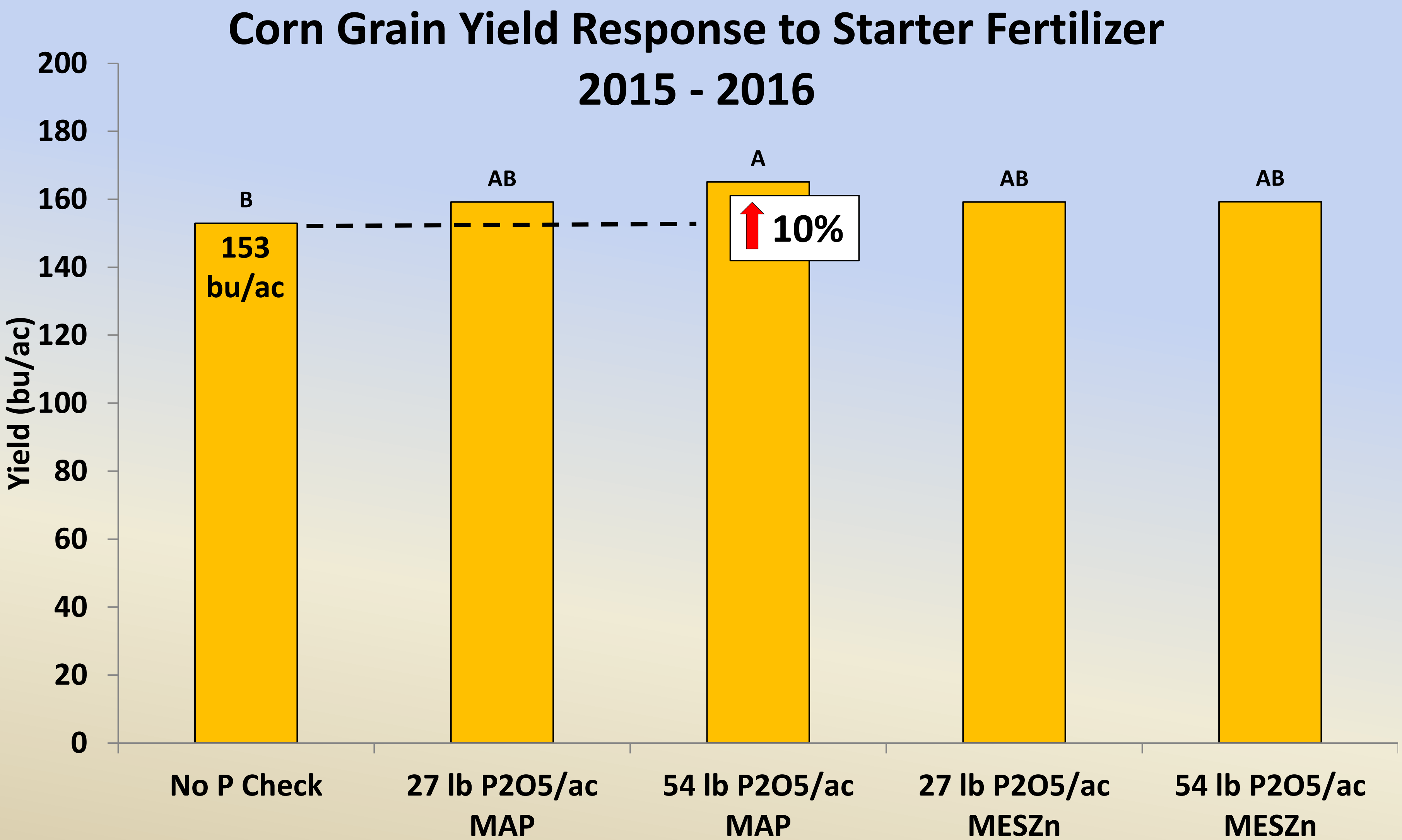
Corn Grain Yield Response to Previous Crop

2015 - 2016



University of Manitoba

Corn Rotation Study



University of Manitoba

Corn Strip Till Study – P Timing & Placement

P fertilization strategies for corn planted in strip tillage vs. conventional tillage

P?

UNIVERSITY OF MANITOBA

Corn Strip Till Study: 2 Previous Tillage Treatments

Rogalsky 2015

UNIVERSITY OF MANITOBA

Corn Strip Till Study: 5 Fertilizer Treatments
(lbs/ac, spring (2” by 1”) and fall application (4-5”))

<u>CONTROL</u>

1. No P Check

<u>MAP (11-52-0) *Only*</u>

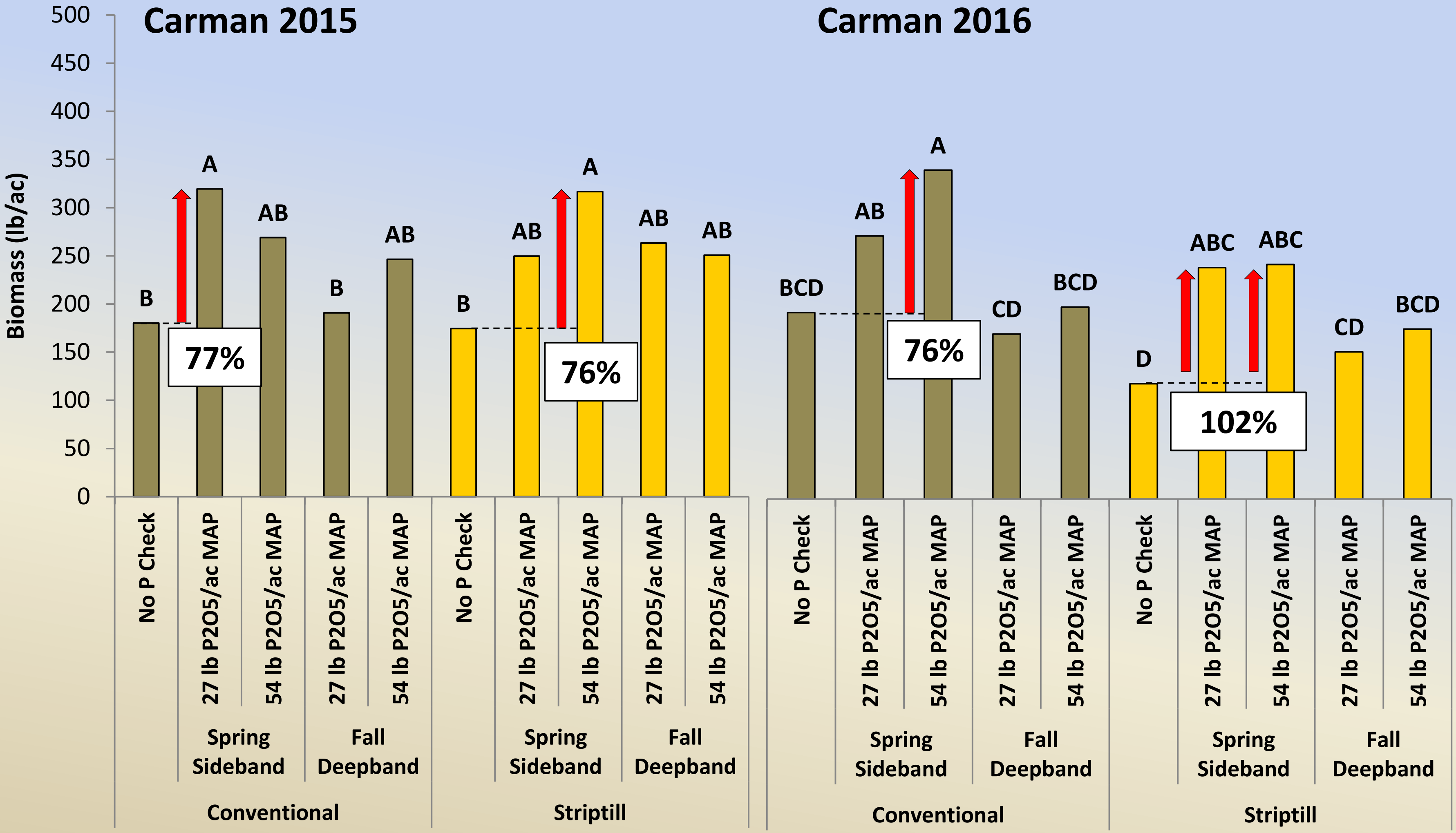
2. 27 P_2O_5 SPRING SB
3. 54 P_2O_5 SPRING SB

4. 27 P_2O_5 FALL DB
5. 54 P_2O_5 FALL DB

UNIVERSITY OF MANITOBA

Corn Strip Till Study

Corn Early Season Biomass (V4) 2015 - 2016

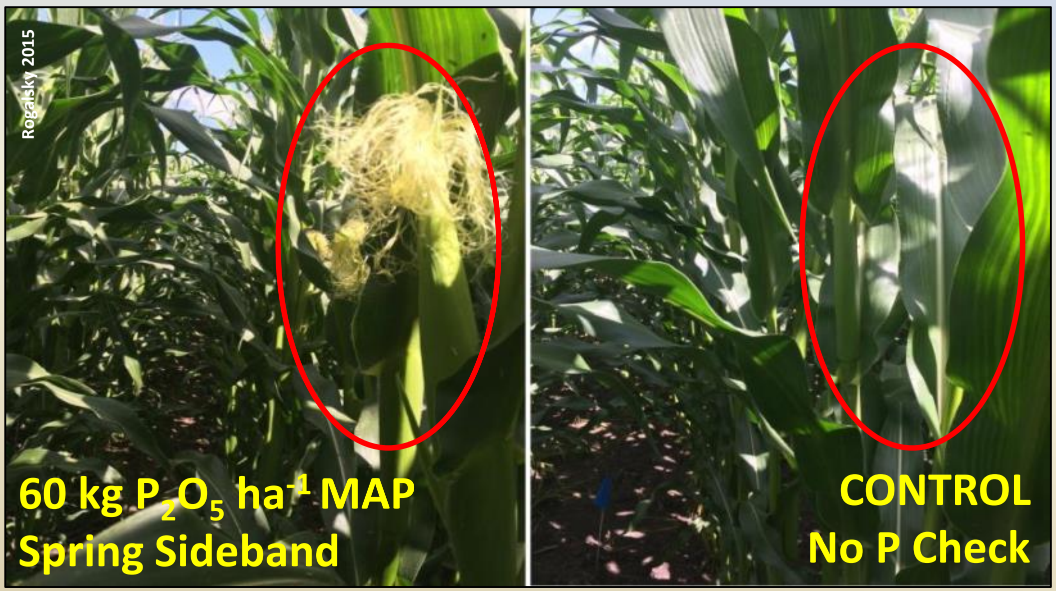


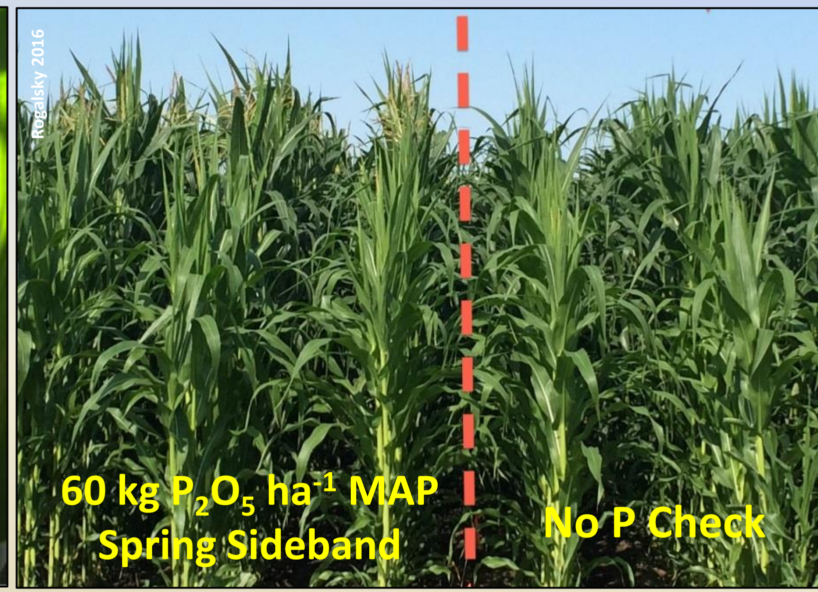
UNIVERSITY OF MANITOBA

Corn Strip Till Study

Silking differences as compared to control plots

Site-year	Maturity Advance (days)	Fertilizer
Carman 2015	+2	All fertilizer treatments
Portage la Prairie 2015	ns	ns
Carman 2016	+3 to 4	Both rates of spring side-banded MAP
Portage la Prairie 2016	ns	ns

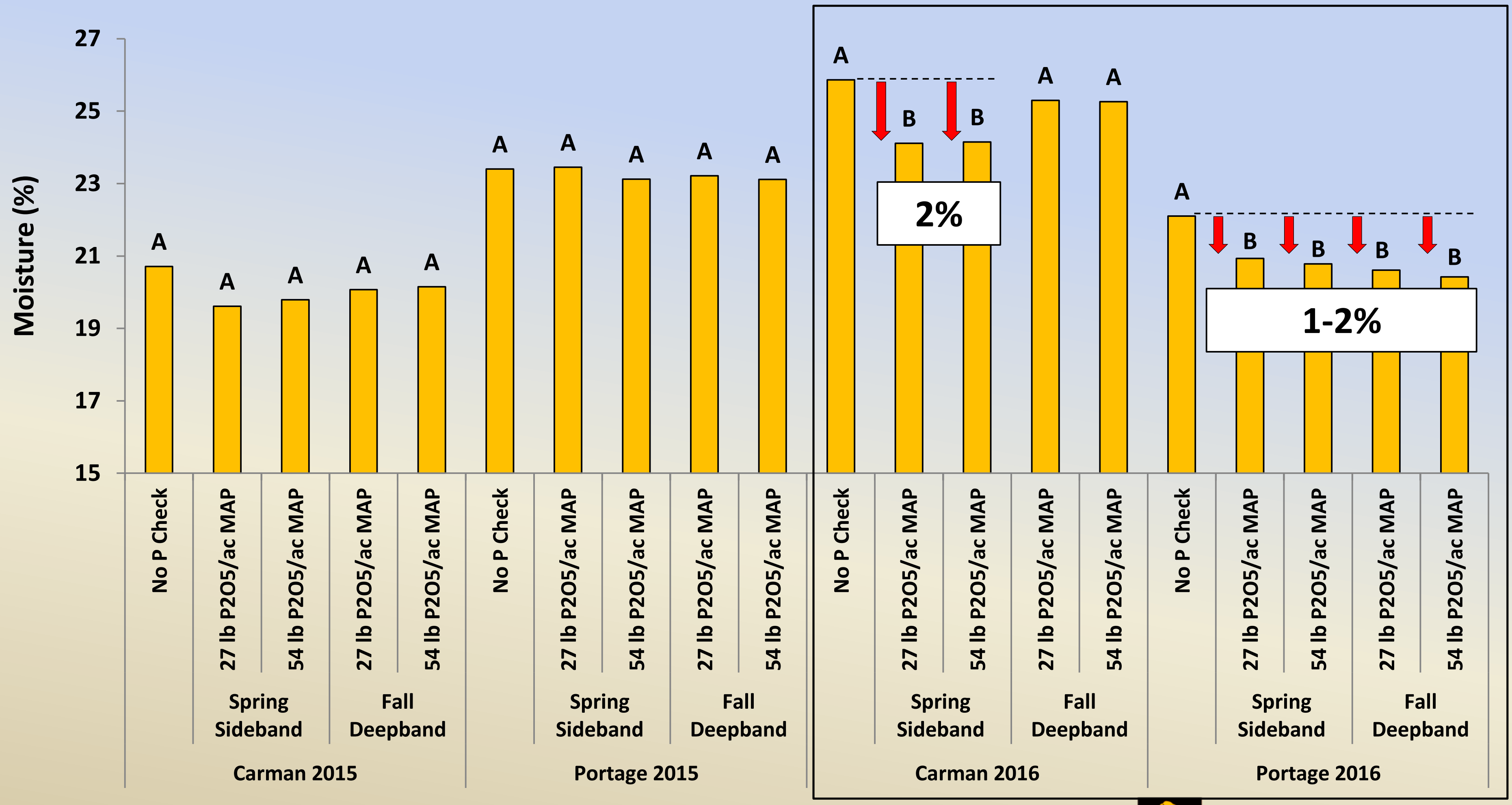




University of Manitoba

Corn Strip Till Study

Kernel Moisture at Harvest
2015 - 2016

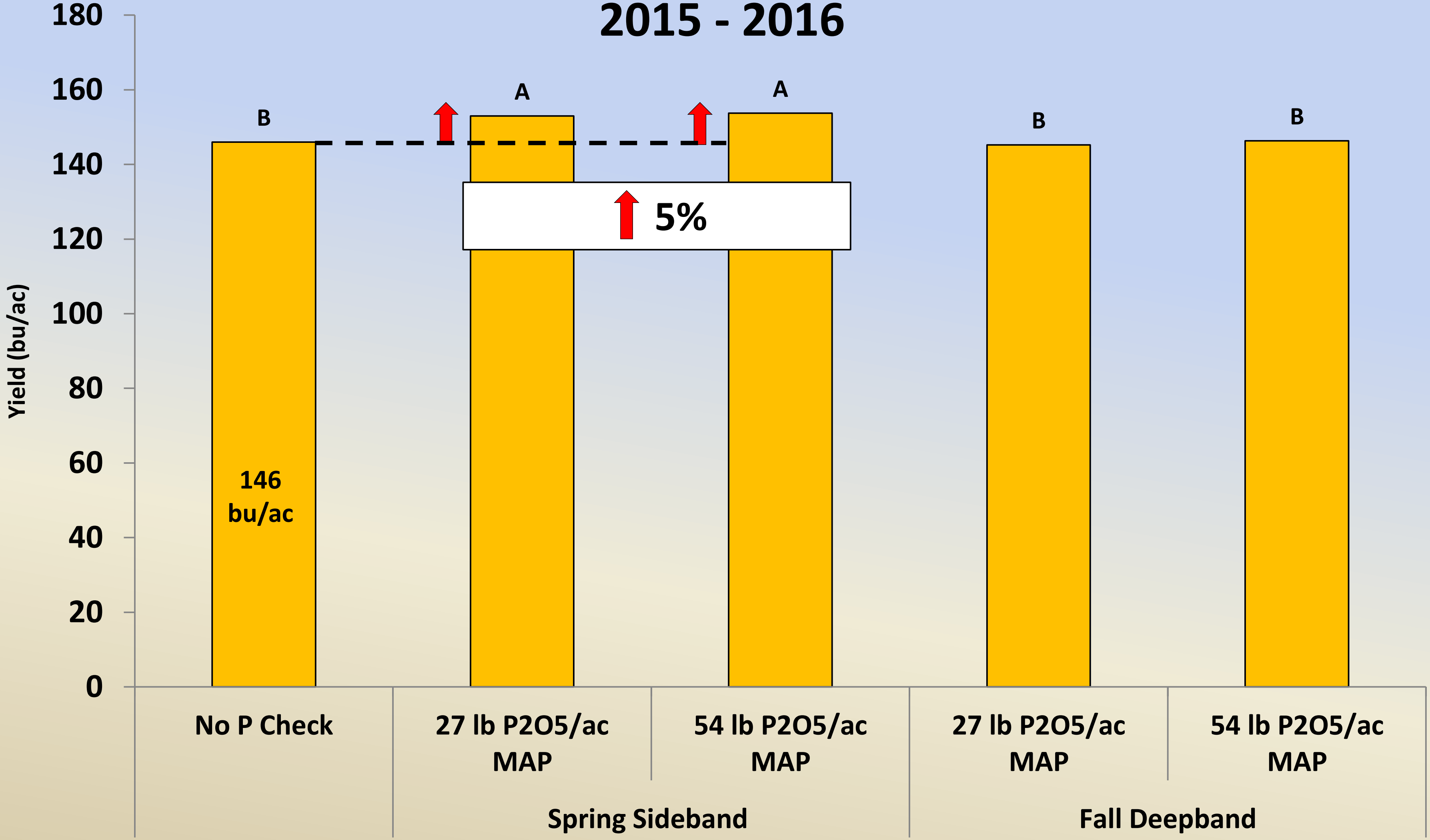


UNIVERSITY OF MANITOBA

Corn Strip Till Study

Corn Grain Yield Response to P

2015 - 2016



UNIVERSITY OF MANITOBA

Manitoba Soybean P Study #1: Effects of P Fertilizer Rate & Placement on Plant Stand and Seed Yield

UNIVERSITY OF MANITOBA

Manitoba Soybean P Study #1: Effects of P Fertilizer Rate & Placement

- Half of the sites tested 10 ppm or less for Olsen P (v. low-low)
- 3 rates of P_2O_5 (0, 40, 80) applied as MAP in SR, SB, or B'cast
- Opener type: knife or disc with row spacing from 7 to 12" (low SBU)

Site	Olsen P (ppm)			Soil Texture	Row Spacing	Seeder Opener
---	2013	2014	2015	----	Inches	Type
Roseisle	N/A	4 (VL)	4 (VL)	Sandy Loam	8	Knife
Melita	3 (VL)	5 (L)	7 (L)	Sandy Clay Loam	9.5	Knife
Brandon	5 (L)	6 (L)	5 (L)	Clay Loam	8	Knife
Carman	N/A	15 (H)	7 (L)	Sandy Clay Loam	8	Knife
Roblin	7 (L)	22 (VH)	8 (L)	Clay Loam	9	Knife
Beausejour	8 (L)	13 (M)	7 (L)	Heavy Clay	9	Disc
Arborg	14 (M)	22 (VH)	14 (M)	Silty Clay	9	Disc
St Adolphe	23 (VH)	25 (VH)	71 (VH)	Heavy Clay	7.3	Knife
Portage	34 (VH)	18 (H)	10 (L)	Clay Loam	12	Disc
Carberry	44 (VH)	11 (M)	15 (H)	Clay Loam	12	Disc

Effect of P rate and placement on soybean seed yield for 28 site years in Manitoba

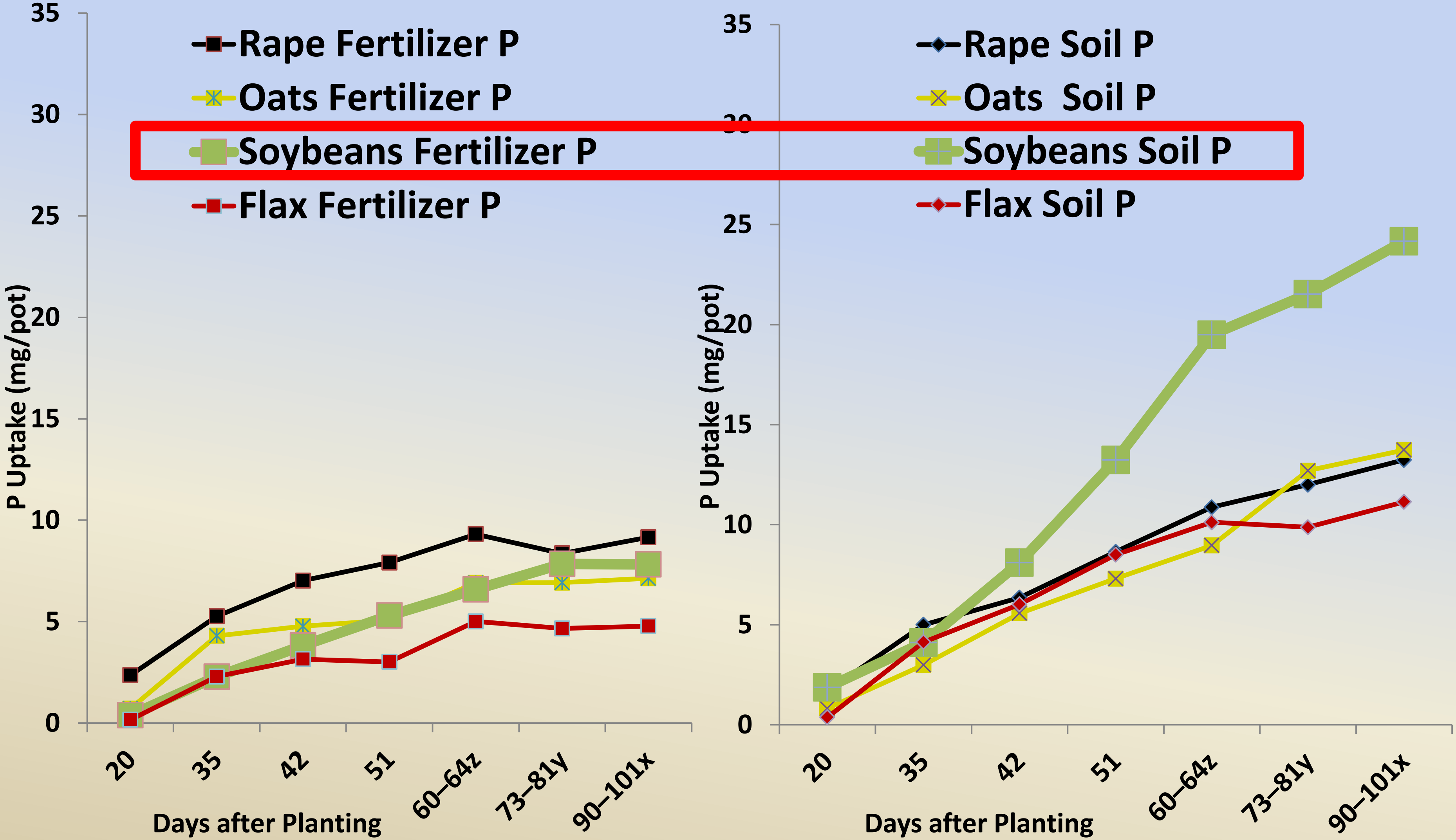
	Year		
	2013	2014	2015
# Sites	8	10	10
Mean Seed Yield (bu/ac)	46	42	51
Control Seed Yield (bu/ac)	23 - 66	18 - 60	37 – 65
# Sites with Yield Increase	0	0	1*
# Sites with Yield Decrease	2**	0	0
Change in Yield	-29 to 36%	0	+15%

* Seed yield increased by 40 and 80 lb P_2O_5/ac at Roseisle 2015

** Seed yield reduced by 80 lb P_2O_5/ac seed-placed, at Melita and Carberry in 2013

University of Manitoba

Why only 1 positive response to P in 28 site years?
Soybeans are efficient feeders for soil P in Manitoba soils



UNIVERSITY OF MANITOBA

(Kalra and Soper 1968)

Manitoba Soybean P Study #2: Soybean response to starter P fertilizer and soil P fertility from historic fertilization practices

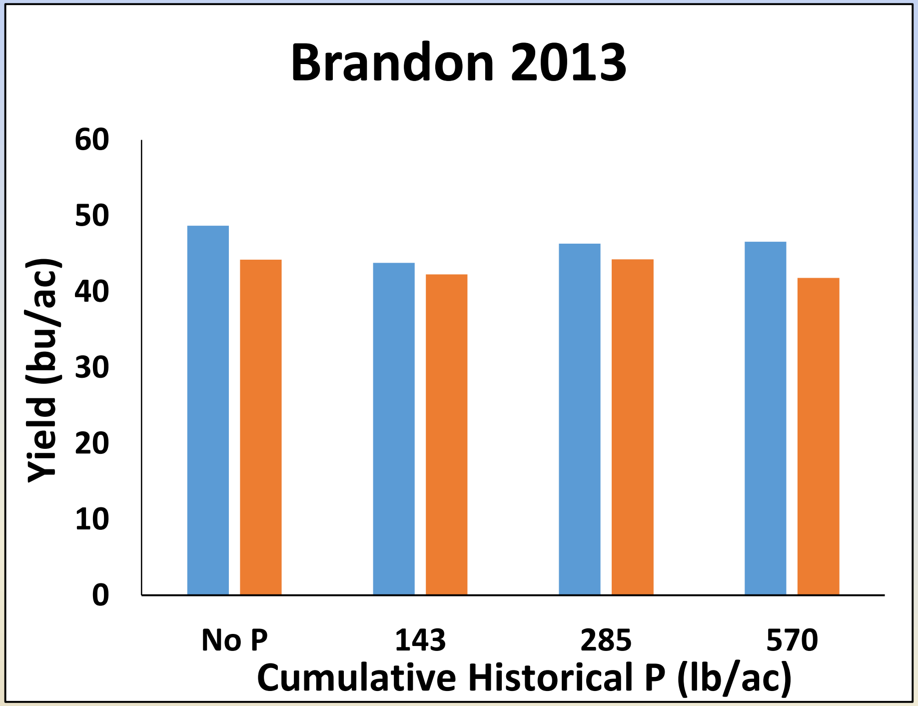
- **Located on three sites for a previous long term P fertilization trial that received 3 rates of MAP fertilizers applied each year, from 2002 until 2009, with total cumulative applications of 320, 640 and 1280 lbs P_2O_5/acre over the 8 year period**
- **No fertilizer P added from 2010-2012**
- **Soybean planted on the same sites in 2013, 2014, 2015**

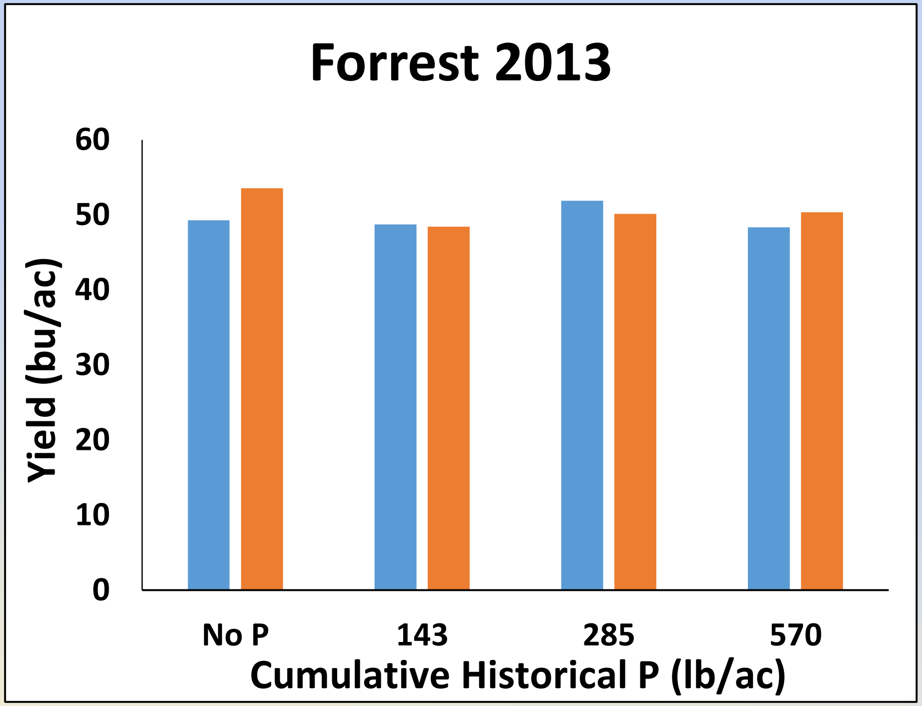
Historical P Applied (lb P/ac)	(lb P_2O_5/ac)	Soil Test Olsen P (ppm) Brandon	Carman	Forrest
0	0	11	20	7
143	320	22	31	15
285	640	33	53	22
570	1280	54	91	40

UNIVERSITY OF MANITOBA

Soybean Seed Yield 2013

- no yield response to starter P or historic P fertility





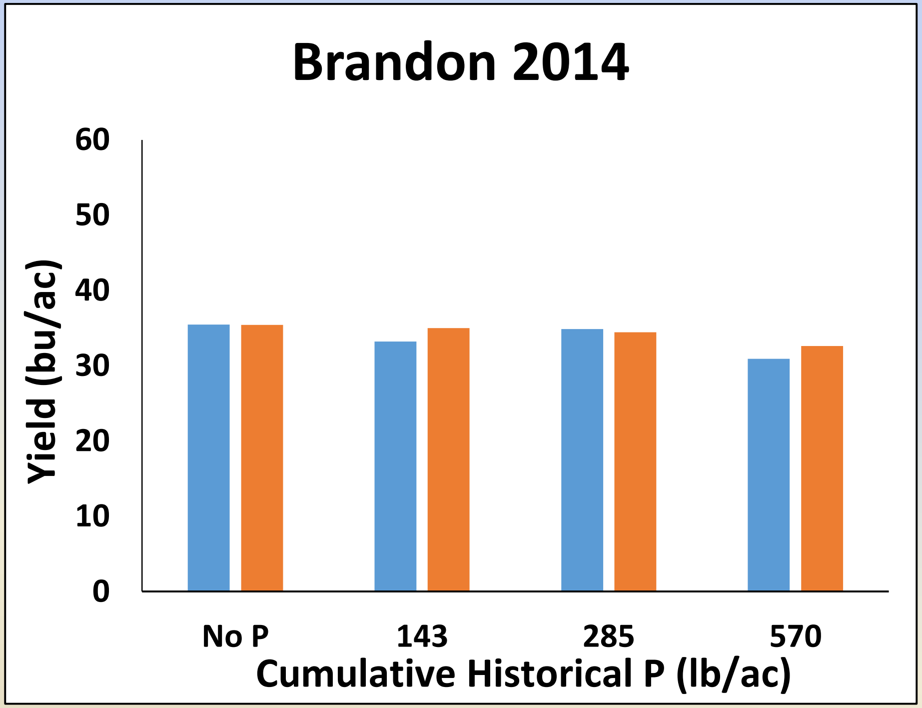
With side-banded starter P (18 lb/ac)

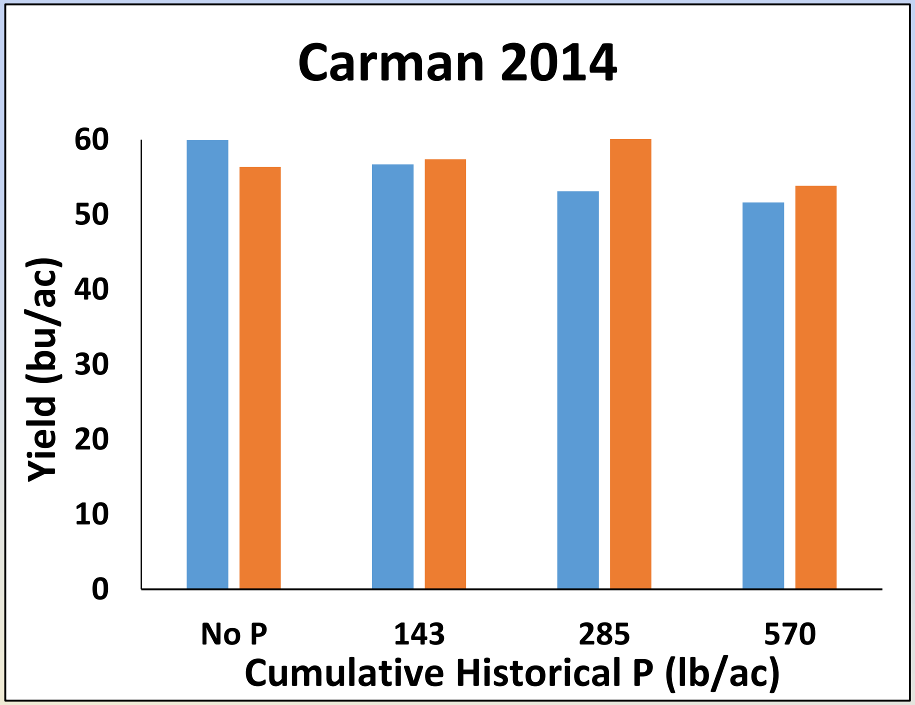
Without starter P

UNIVERSITY OF MANITOBA

Soybean Seed Yield 2014

- no yield response to starter P or historic P fertility





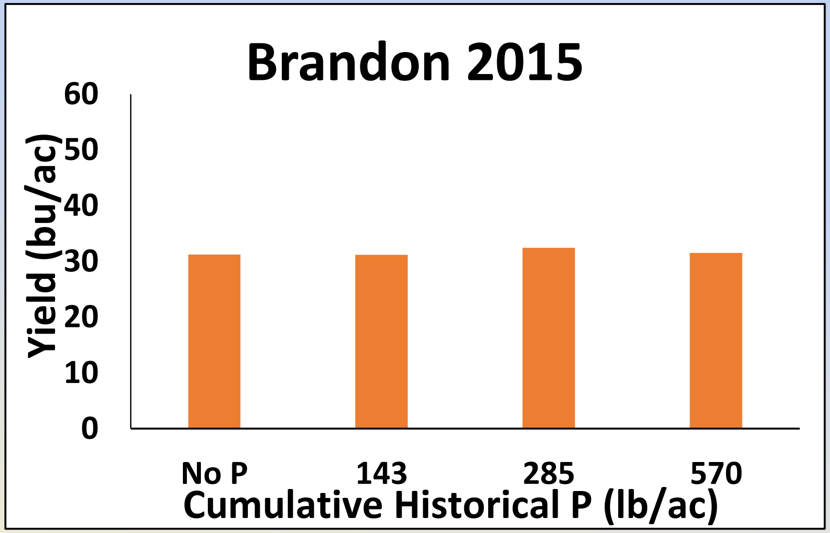
With side-banded starter P (18 lb/ac, for 2nd year)

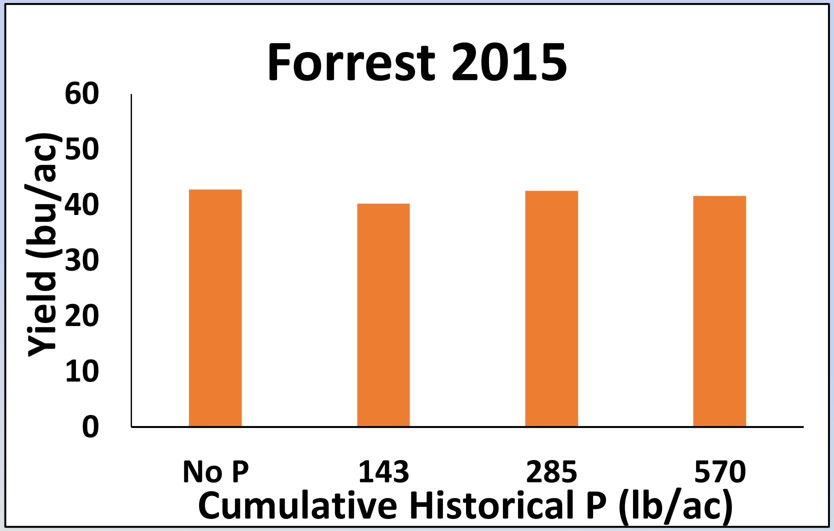
Without starter P

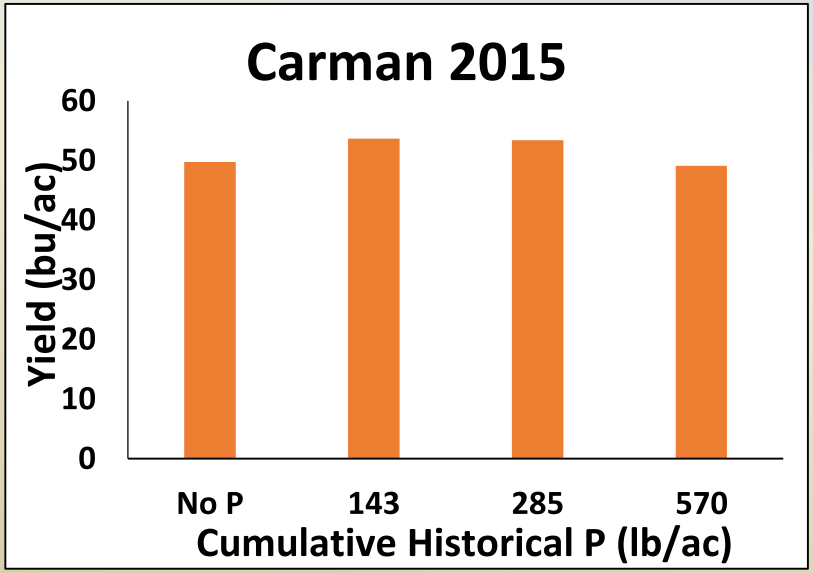
University of Manitoba

Soybean Seed Yield 2015

- no yield response to historic P fertility







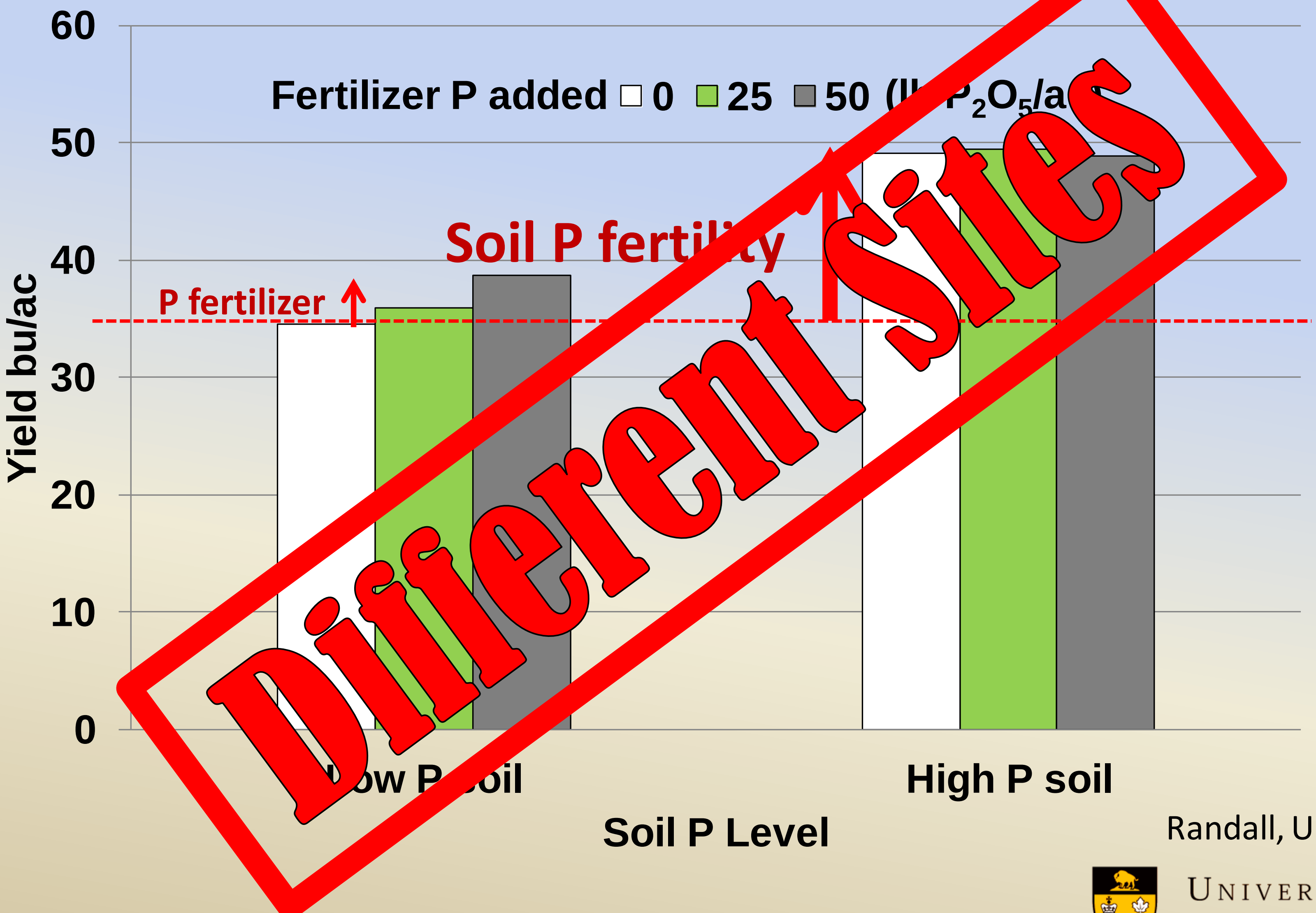
UNIVERSITY OF MANITOBA

Summary and Conclusions for Manitoba Soybean P Study #2

- The soil test threshold for soybean yield responses to long term soil P fertility and/or P fertilizer appears to be very low in Manitoba soils, lower than those in the soils tested so far (7, 11 & 20 ppm Olsen P)
- Observations of higher soybean yields on soils with higher P fertility (e.g., manured soils) may be due to other factors

University of Manitoba

In Minnesota research, soybean response to soil P fertility was greater than to P fertilizer



Randall, U of Mn

University of Manitoba

Soybeans may not “care” about P fertilizer, but what about the crop after soybeans?

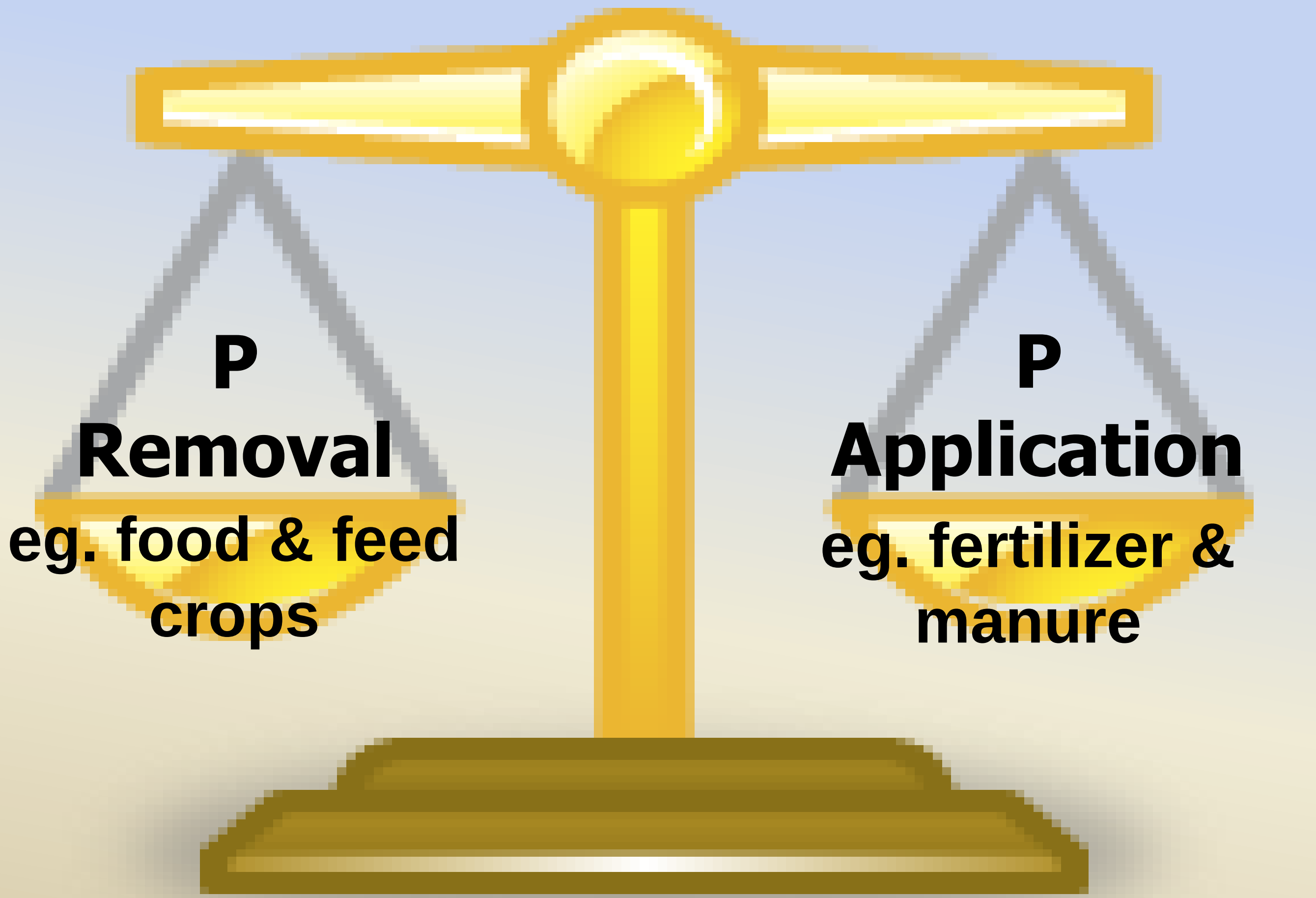
The phosphorus deficit hangover ...

softpedia.com

www.deviantart.com

UNIVERSITY OF MANITOBA

Balancing P application with crop removal is essential to avoid excessive accumulation or depletion of P in soil



University of Manitoba

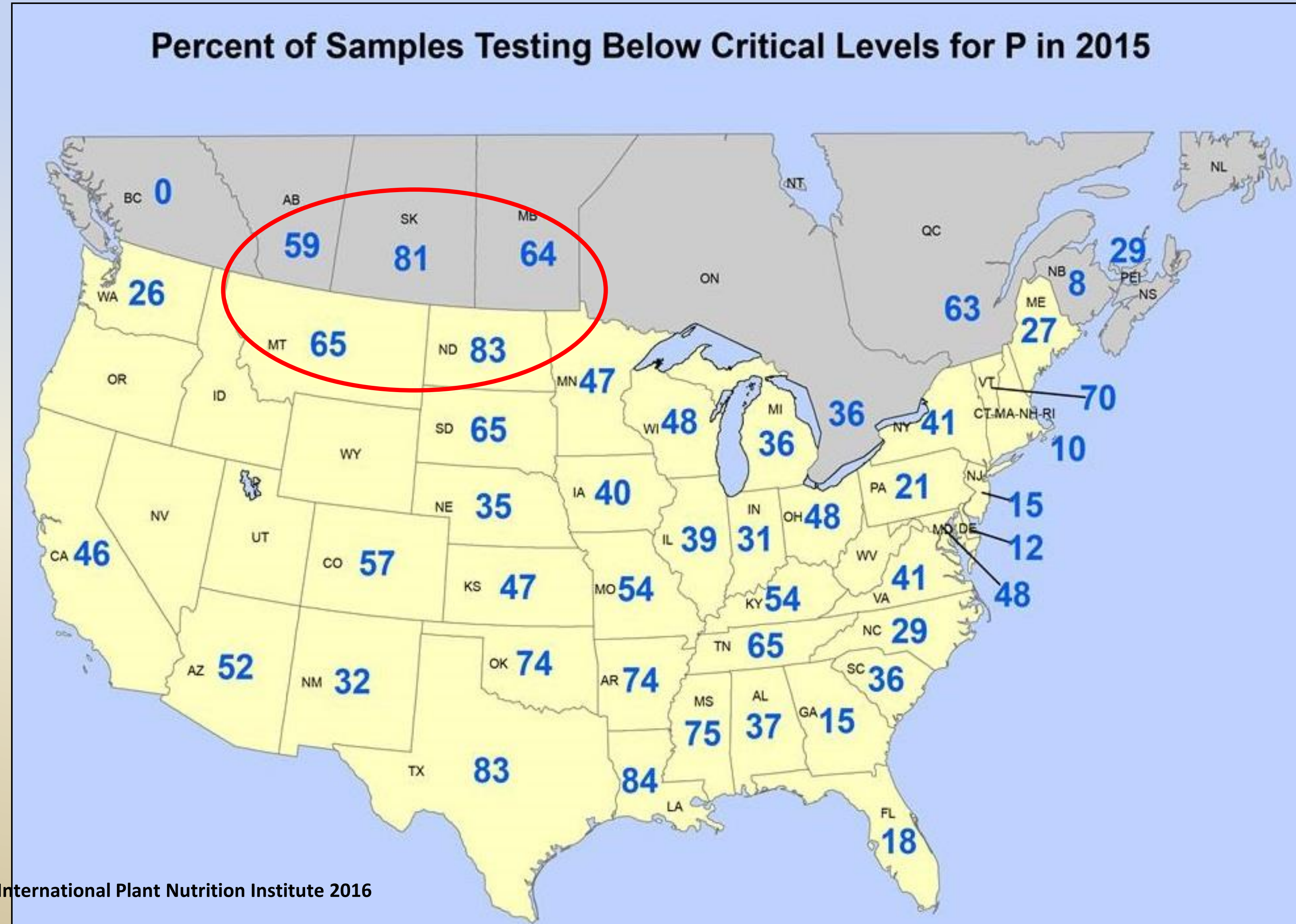
P Removal by Annual Crops

Crop	Yield Level/Acre	P_2O_5 Removed by Crop lb/ac	lb/bu
Wheat	45 bu	36 (26)*	0.59
Canola	45 bu	75 (46)	1.0
Soybeans	40 bu	43 (34)	0.85
Barley	80 bu	45 (34)	0.43
Peas	50 bu	43 (34)	0.68
Oats	100 bu	41 (26)	0.26
Corn	100 bu	63 (44)	0.44

*Removed in grain, only

UNIVERSITY OF MANITOBA

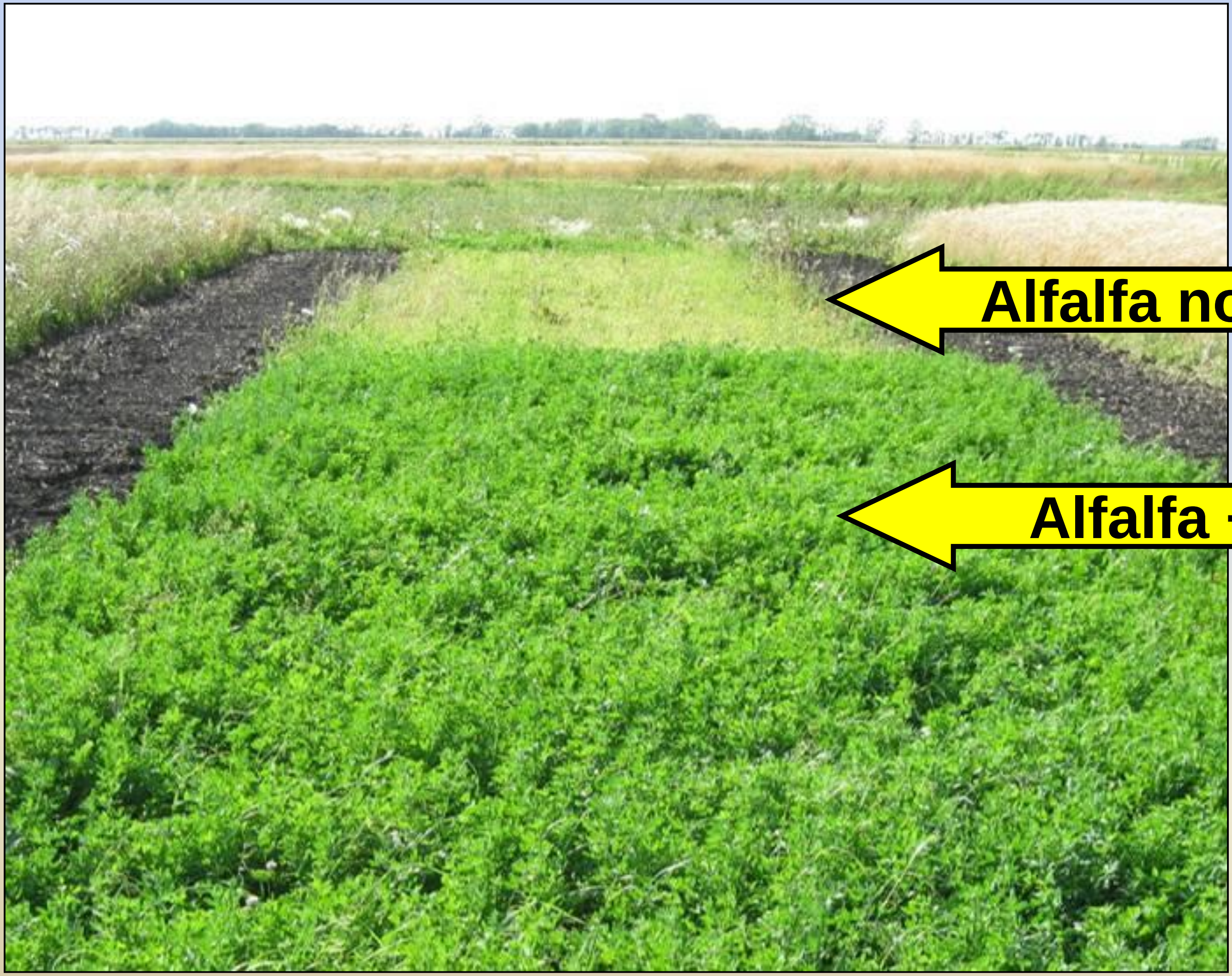
Majority of Prairie Soils Are Deficient in P According to % Less Than Critical Level



International Plant Nutrition Institute 2016

Clayton Harder's canola field, north of Wpg.
With and Without 40 lbs P_2O_5 + 12 lbs S/acre

Dr. Martin Entz's long term organic rotation at U of MB demonstrates the importance of P replacement



University of Manitoba

Effect of legume green manures on long term wheat yields in SK

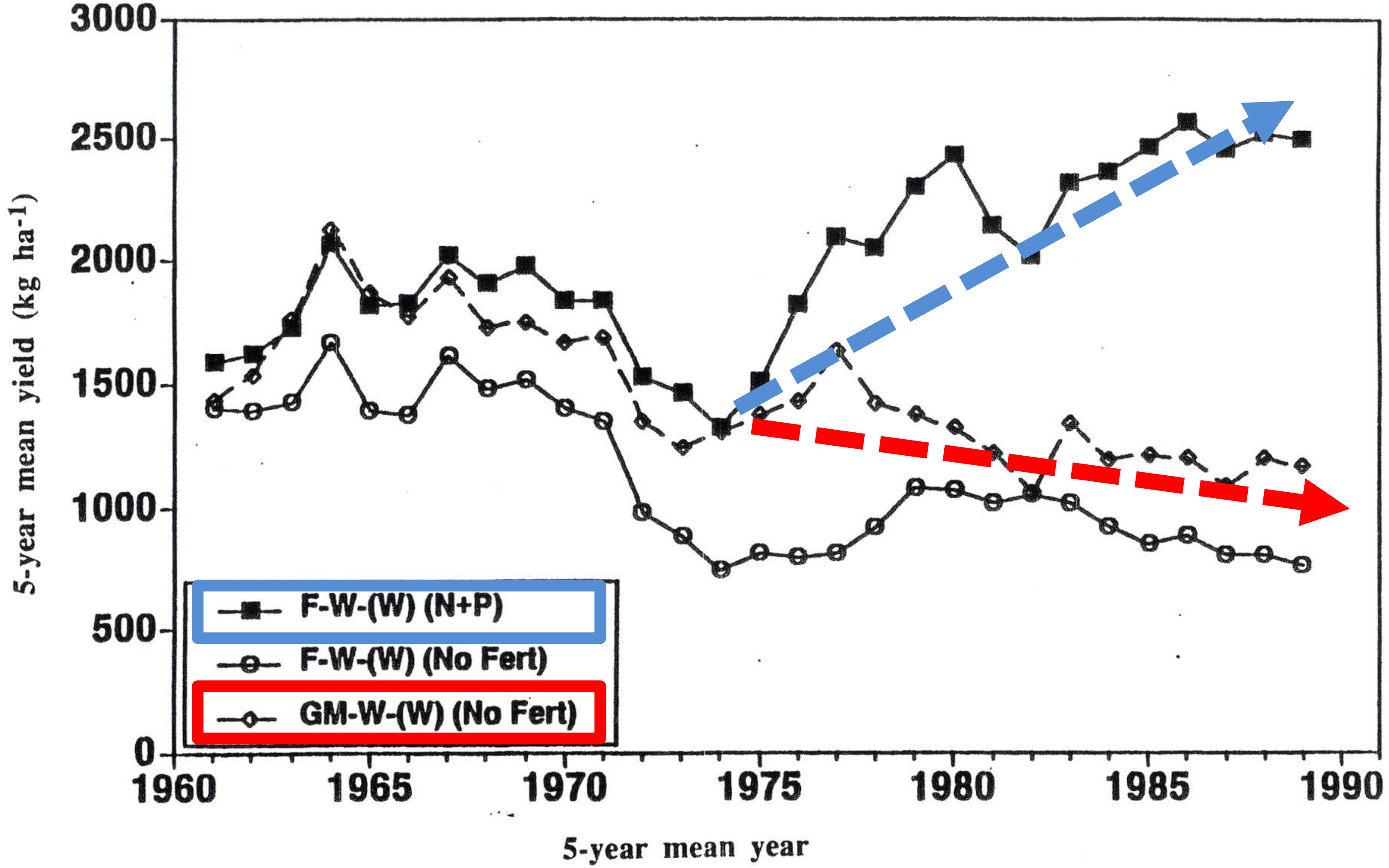
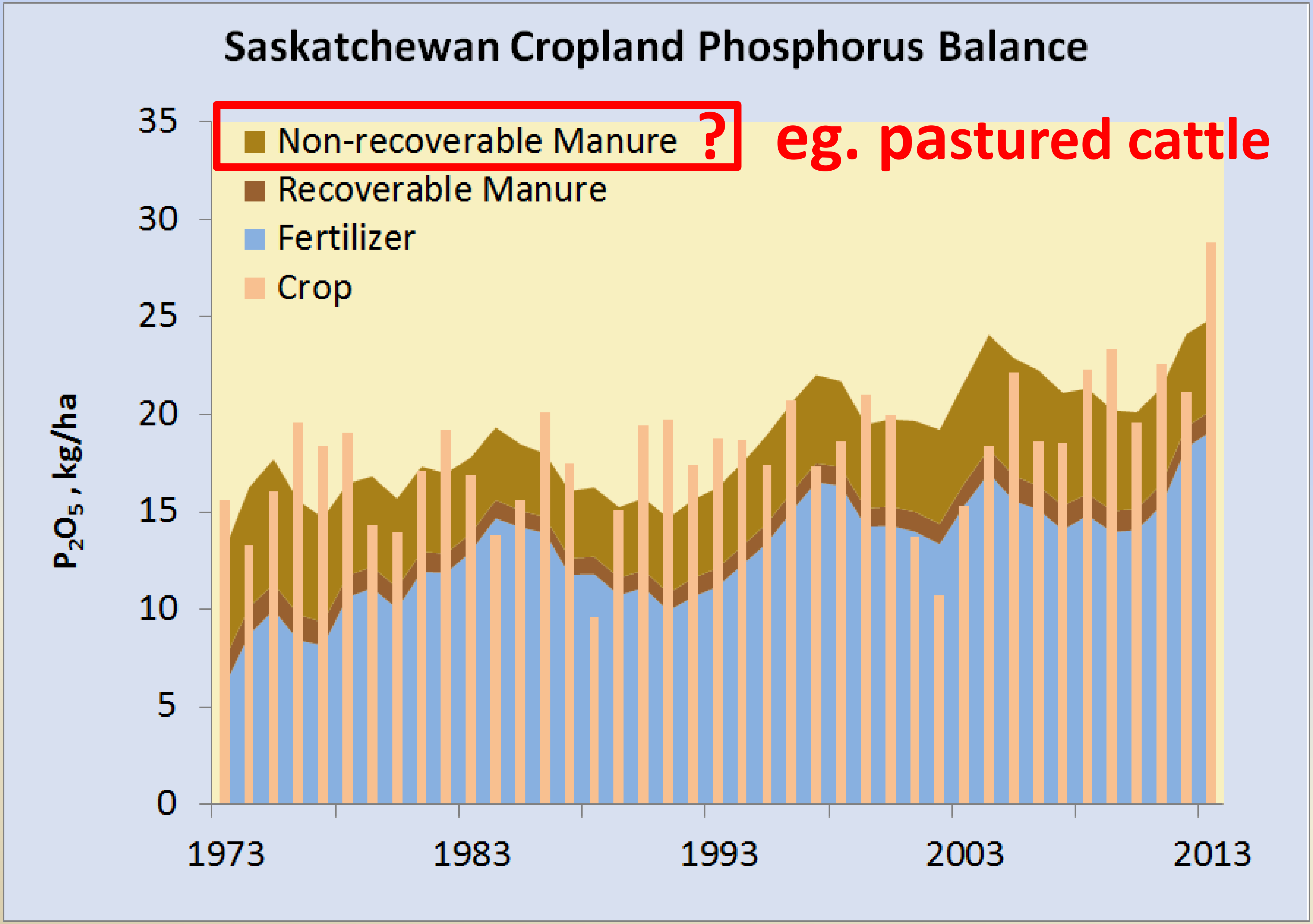


Figure 1. Yields of stubble wheat crops in fallow-wheat-wheat (F-W-W), fallow-wheat-wheat plus fertilizer (F-W-W (N+P)) and green manure-wheat-wheat (GM-W-W) rotations at Indian Head (Black soil zone) (C.A. Campbell, unpublished data).

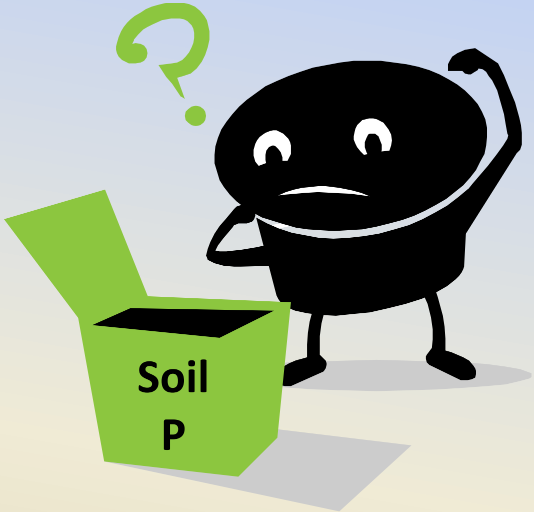
Cowell & Doyle 1993



International Plant Nutrition Institute http://phosphorus.ipni.net/article/NANE-3095

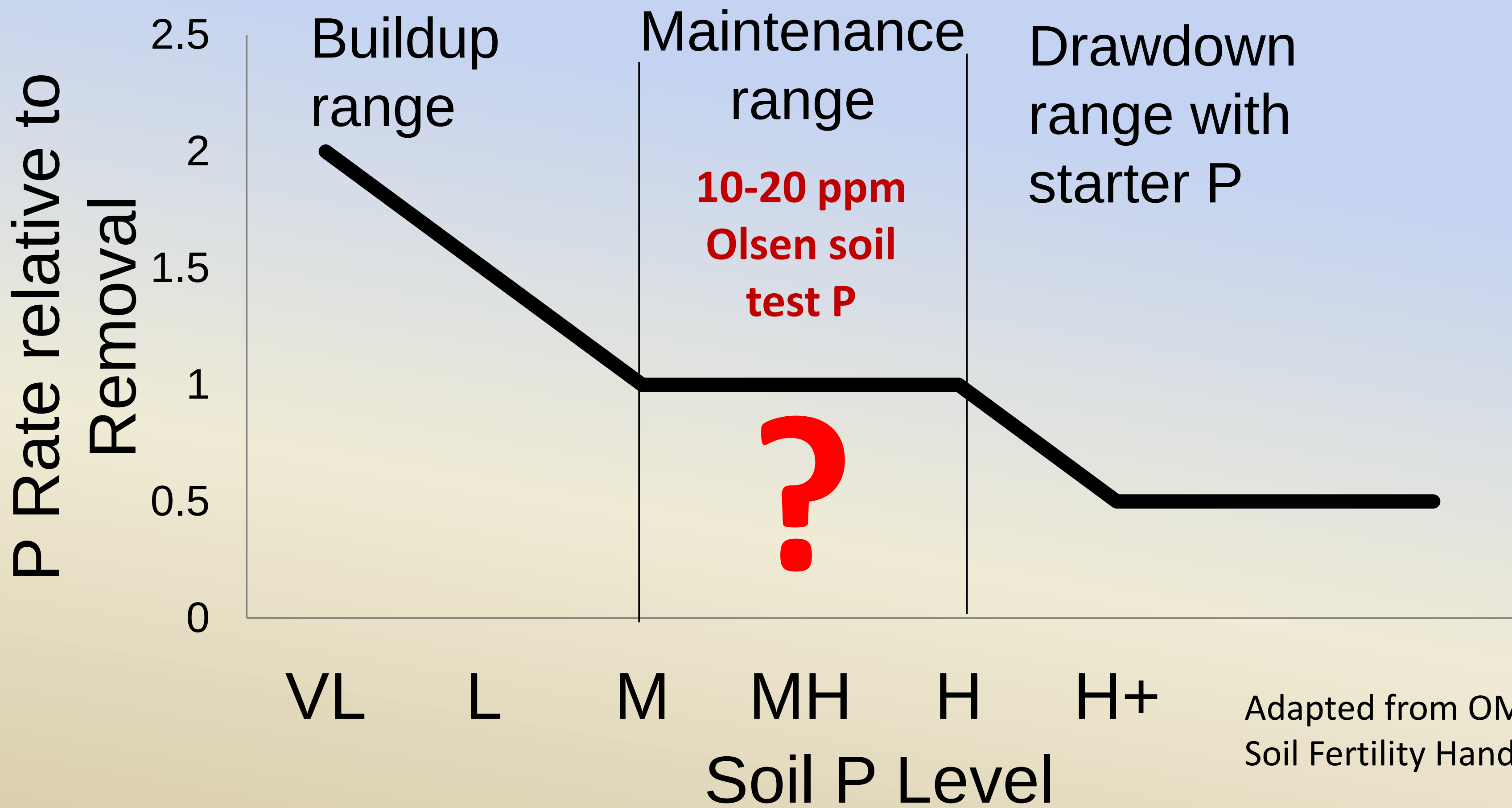
University of Manitoba

Manitoba's new recommendation for P fertil'n strategy: Phosphorus balance should be managed through the rotation … not just on a single crop basis



- **What is the current soil P level?**
  - **If excess, can draw down by using only starter P**
  - **If near optimum, can balance input and removal**
  - **If low, may want to build by applying fertilizer or manure P in excess of crop removal**

A fertilization concept to move soil P levels into an optimum range over time

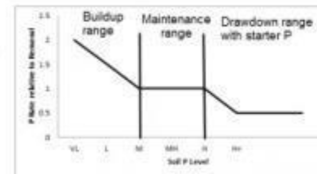


Adapted from OMAFRA Soil Fertility Handbook

UNIVERSITY OF MANITOBA

MANITOBA Pulse Soybean GROWERS

Phosphorus Fertilization Strategies



Did you know? Soybeans remove 0.84 lbs P per bushel, which means a 40 bu/ac soybean crop removes 34 lbs P/ac. Attention must be paid to ensure a proper fertilization strategy is adopted to ensure application rates are meeting removal rates through the entire crop rotation – learn more below.

Manitoba fertilizer phosphorus (P) guidelines have not been updated since 1992 and some troubling trends have been identified:

- In several of the past years the crop removal of P has surpassed the application rate of fertilizer P
- More soil test values are declining into the LOW range in some areas of Manitoba

This decline in soil test P levels (STP) may arise for a number of reasons:

- Changing crop acreages– from relatively low P removal crops of cereals and flax to canola, soybeans and corn
- Move to low disturbance seeders and planters with narrow openers and wide row spacings (low seedbed utilization) which limit the safe rate of seed row applied fertilizer, especially with sensitive crops such as canola and soybeans
- Promotion and adoption of low P rate starter fertilizers that do not replace P that is removed by crops
- Increase in grain yields since development of original MAFRD recommendations in the early 1990s due to breeding (ie introduction of hybrid canola, general purpose spring wheats etc.) and technology (ie fungicide use)
- Provincial recommendation tables do not include yield adjustment factors, so rates have been inadequate to meet current yield levels, let alone match rates of P removal

Thinking about your cropping system, or that your client, does P applied equal P removed? Or are crop removal rates exceeding P applied, leading to a negative soil P balance? Use the Interactive Phosphorus Balance Calculator to determine your annual P balance:

Interactive Phosphorus Fertilization Calculator

Phosphorus Recommendation Strategies for Manitoba

Manitoba Soil Fertility experts have collaborated to develop "Phosphorus Fertilization Strategies for Long Term Agronomic and Environmental Sustainability" which outlines

P fert'n for rotation interactive v4.xlsx - Microsoft Excel

Phosphorus Balance Calculation for a Rotation (Version 4 - October 1, 2014)

Crop	Typical Yield	Yield Units	P Applied	P Removed* per unit	P Removed* per acre	Annual Balance
			------------ (lb P_2O_5/ac) ------------			
HR Spring wheat	60	bu/ac	30	0.59	35	-5
Winter wheat	75	bu/ac	30	0.51	38	-8
Barley		bu/ac		0.42	0	0
Oats		bu/ac		0.26	0	0
Canola	40	bu/ac	20	1.04	42	-22
Soybeans	40	bu/ac	10	0.84	34	-24
Peas		bu/ac		0.69	0	0
Flax		bu/ac		0.65	0	0
Corn (grain)		bu/ac		0.44	0	0
Other**				0.00	0	0
Total for Rotation			90		149	-59

Notes: Does not account for nutrients removed when straw or chaff is removed or burned

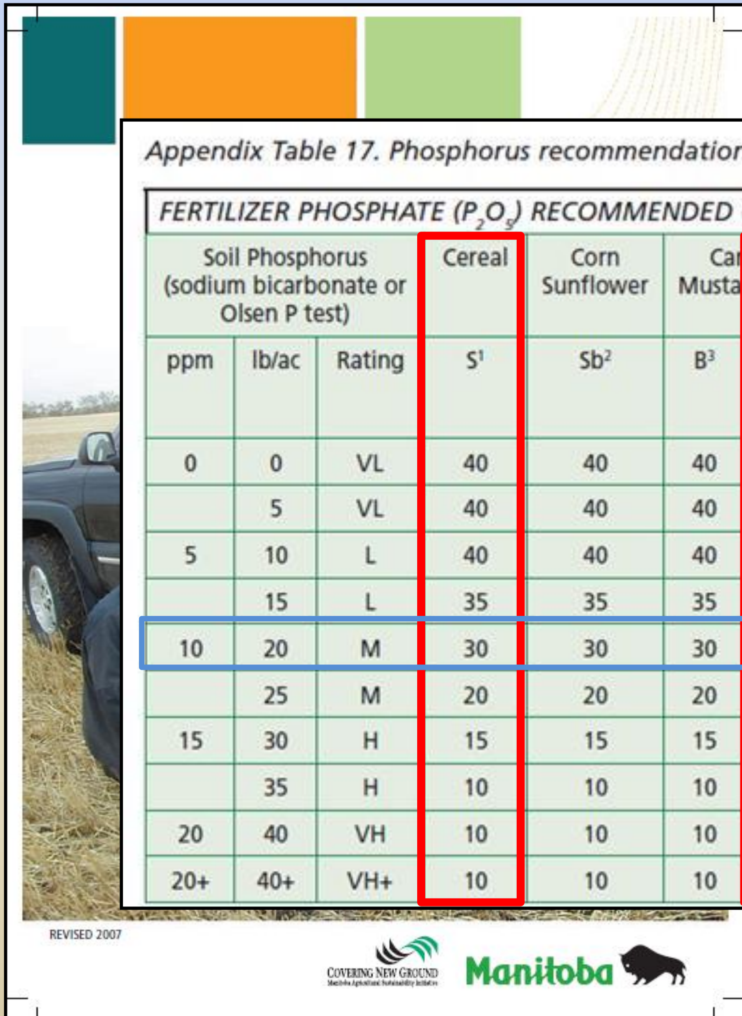
Fill in any of the blue cells for typical rotation, yields, and P appl'n

*P removal figures are estimates from the Manitoba Soil Fertility Guide.

**For nutrient removal in other crops see table in next worksheet.

Interactive P balance worksheet | Nutrient removal table

P sufficiency strategy for short term (fertilizing for optimum economic responses in first year after application) often decreases P fertility for long term



Appendix Table 17. Phosphorus recommendations for field crops based on soil test levels and placement[76].

FERTILIZER PHOSPHATE (P_2O_5) RECOMMENDED (lb/ac)

Soil Phosphorus (sodium bicarbonate or Olsen P test)			Cereal	Corn Sunflower	Canola Mustard Flax		Buckwheat Fababeans		Potatoes		Peas Lentils Field beans[†] Soybeans[†]		Legume forages		Perennial grass forages	
ppm	lb/ac	Rating	S[1]	Sb[2]	B[3]	S[1]	B[3]	S[1]	B[3]	PPI[4]	B[3]	S[1]	seeding PPI[5]	Est. stand BT[6]	seeding PPI[5]	Est. stand BT[6]
0	0	VL	40	40	40	20	40	20	55	110	40	20	75	55	45	30
	5	VL	40	40	40	20	40	20	55	110	40	20	75	55	45	30
5	10	L	40	40	40	20	40	20	50	100	40	15	75	55	45	30
	15	L	35	35	35	20	35	20	45	90	35	15	65	50	35	20
10	20	M	30	30	30	20	30	20	45	90	30	10	60	40	30	20
	25	M	20	20	20	20	20	20	40	80	20	10	50	35	20	15
15	30	H	15	15	15	0	15	20	35	70	15	0	45	30	15	10
	35	H	10	10	10	0	10	20	30	60	10	0	30	20	0	0
20	40	VH	10	10	10	0	10	20	30	60	10	0	30	20	0	0
20+	40+	VH+	10	10	10	0	10	20	30	60	10	0	25	20	0	0

UNIVERSITY OF MANITOBA

Rotational Fertilization Strategies for P Balance Based on MB SFG Rec. for 10 ppm Olsen P

Annual & Overall P Balance for P Strategies in 4 Year Rotation					
Crop	Yield	MB SFG	Max Seed Row P	N-Based Manure in 1st yr	P Maint. with Sideband
	(bu/ac)	------------- (lb P_2O_5/ac) -------------			
GP spring wheat	60	-5			
Canola	40	-20			
Winter wheat	75	-8			
Soybeans	35	-20			
4 Year Total		-53			

* Using values of 0.59, 1.0, 0.51, 0.85 lb P_2O_5/bu respectively for grain only

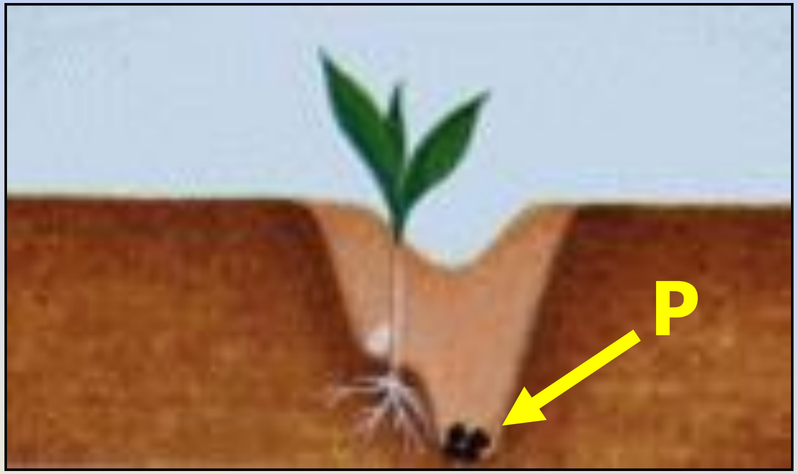
UNIVERSITY OF MANITOBA

Why not simply broadcast P?

UNIVERSITY OF MANITOBA

Almost all fertilizer P in the Canadian Prairies is banded under soil surface, in or near seed, at planting

- Agronomically beneficial, especially in cold soils in areas with short growing season
- Environmentally beneficial because P placed under soil surface after spring snowmelt runoff



Broadcasting P fertilizer, especially in conservation tillage systems leaves water soluble P on the soil surface ... prone to runoff ... especially if applied in fall

An invitation to regulation ...

UNIVERSITY OF MANITOBA

Why is phosphorus balance important?

Food - P is a unique element that is essential for almost all life

Source: Christiansen/ Scientific American

Water - small amounts of excess P cause big problems with water quality

Photo: MB Conservation

University of Manitoba

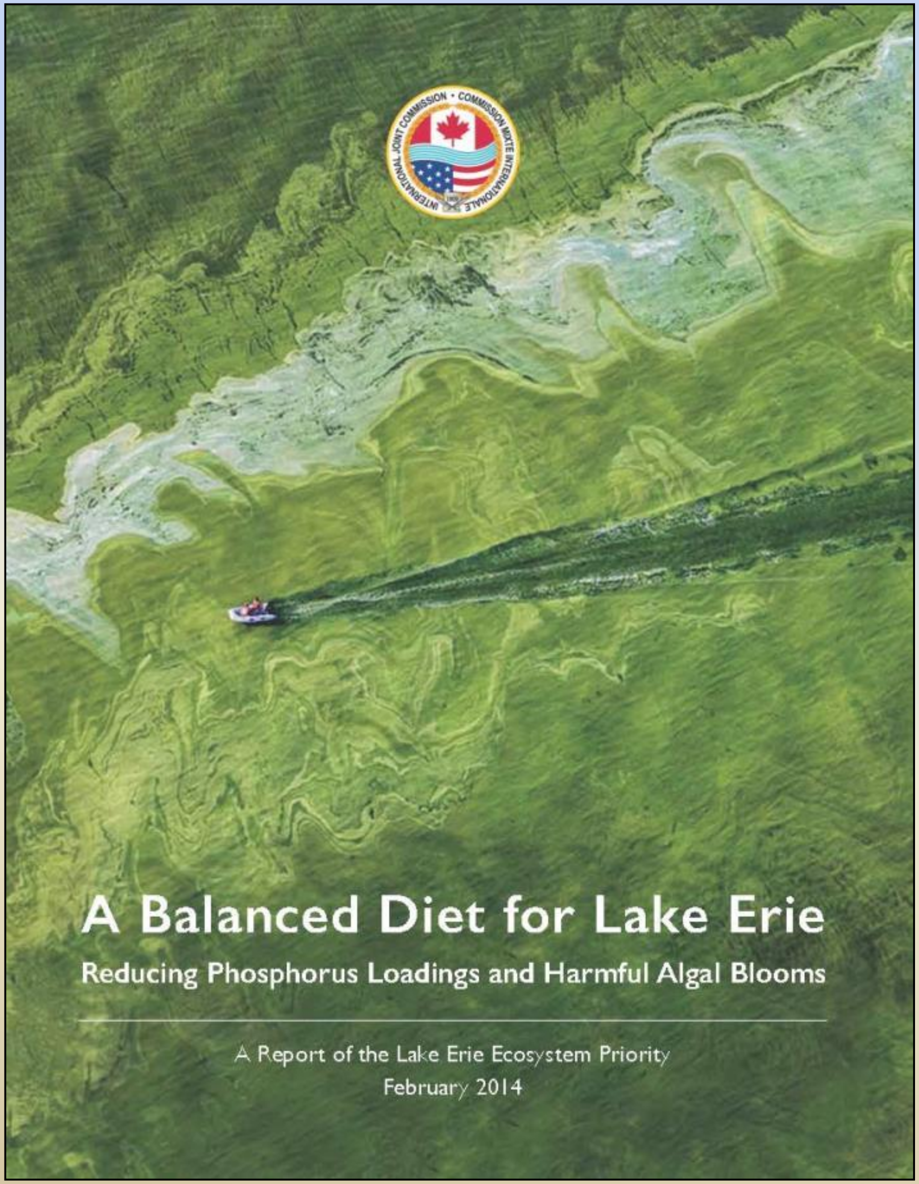
Main Problem: Excess P and "Algae"

"Eutrophication" occurs at very low conc'ns of P (20-50 ppb):

- Blue-green "algae" (cyanobacteria)
- Oxygen Depletion
  - Fish kills
- Nerve and Liver Toxins
  - Livestock & wildlife mainly at risk

University of Manitoba

International Joint Commission Report on Improving Water Quality in Lake Erie – February 2014



"The control of phosphorus in agricultural operations must focus on changes in agricultural practices that have been implemented in recent decades, such as <u>increased prevalence of fall application of nutrients, applying two years' worth of fertilizer in a single application, and broadcast application</u>."

page 7 of International Joint Commission (2014). A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms. Report of the Lake Erie Ecosystem Priority.

University of Manitoba

Excess P & toxic blue-green algae in Lake Erie shuts down water supply to Toledo, Ohio – August 2014

UNIVERSITY OF MANITOBA


Fertilizer Application Patterns and Trends and Their Implications for Water Quality in the Western Lake Erie Basin

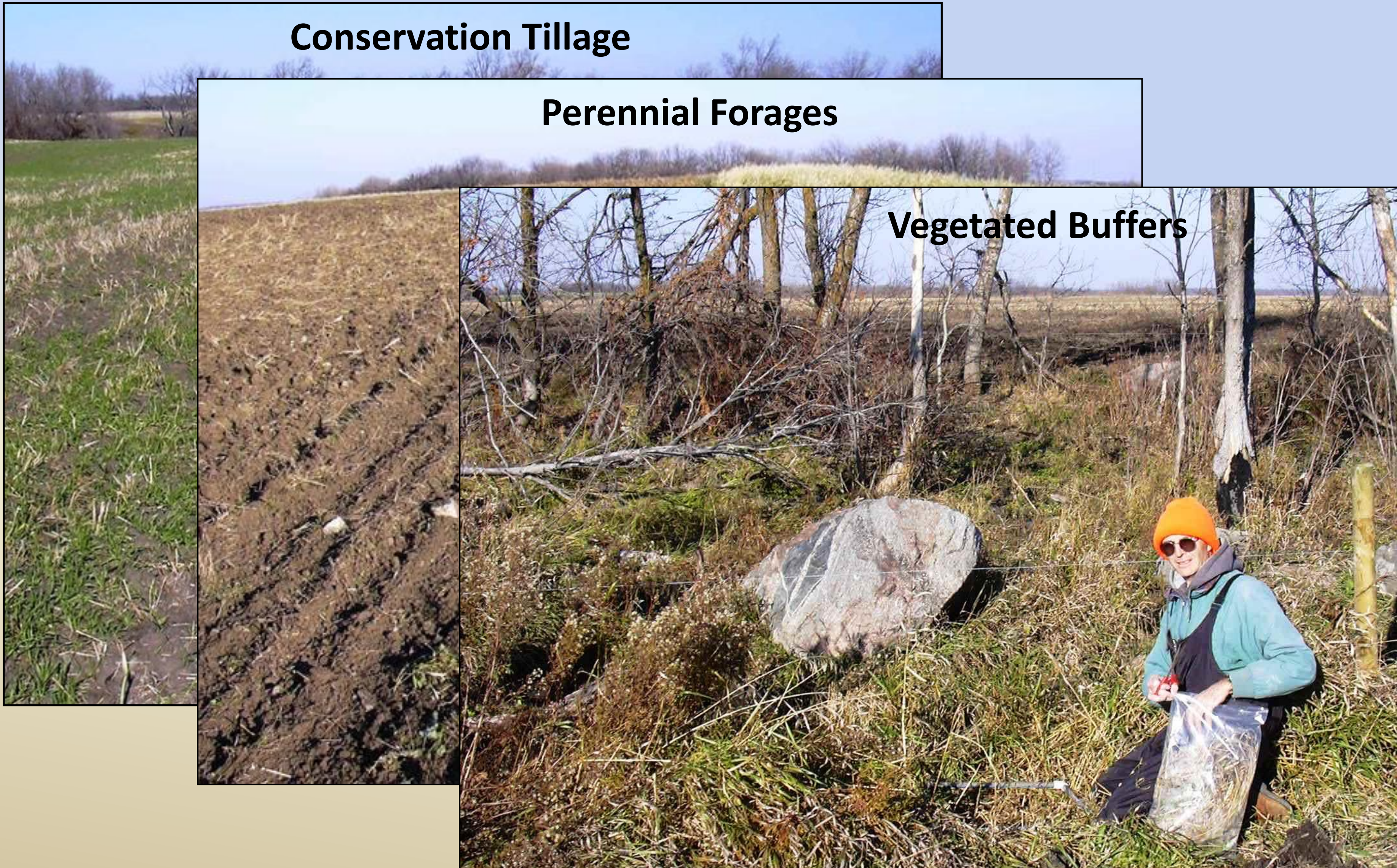
February 2018

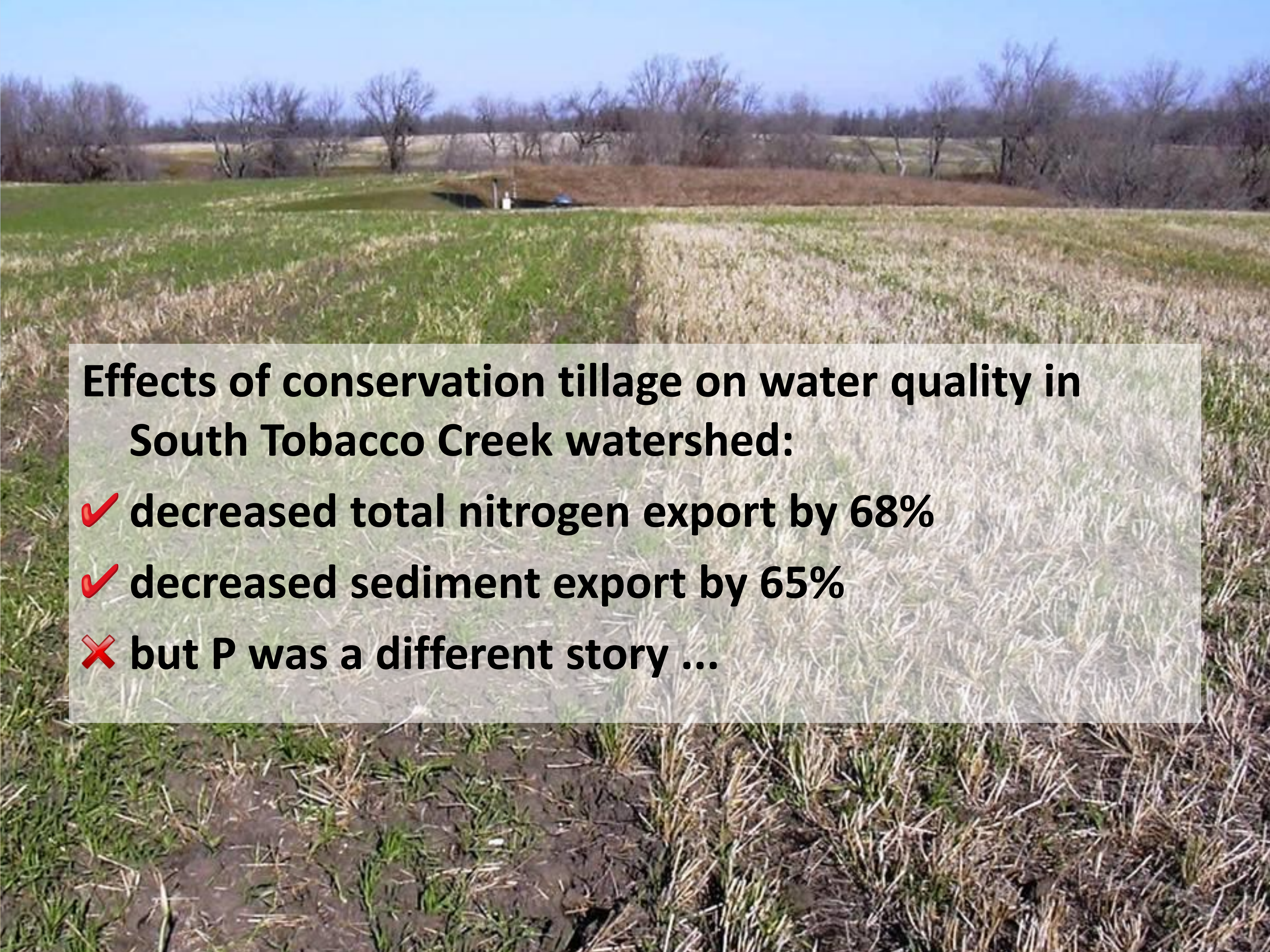
INTERNATIONAL JOINT COMMISSION • COMMISSION MIXTE INTERNATIONALE
Canada and the United States   Canada et États-Unis

p 31: "Kalcic et al. (2016) found that widespread use of multiple best management practices (BMPs), <u>in particular subsurface fertilizer placement,</u> would be needed to approach phosphorus reduction targets in the Western Lake Erie Basin."

UNIVERSITY OF MANITOBA

Managing P loss with traditional soil and water conservation BMPs

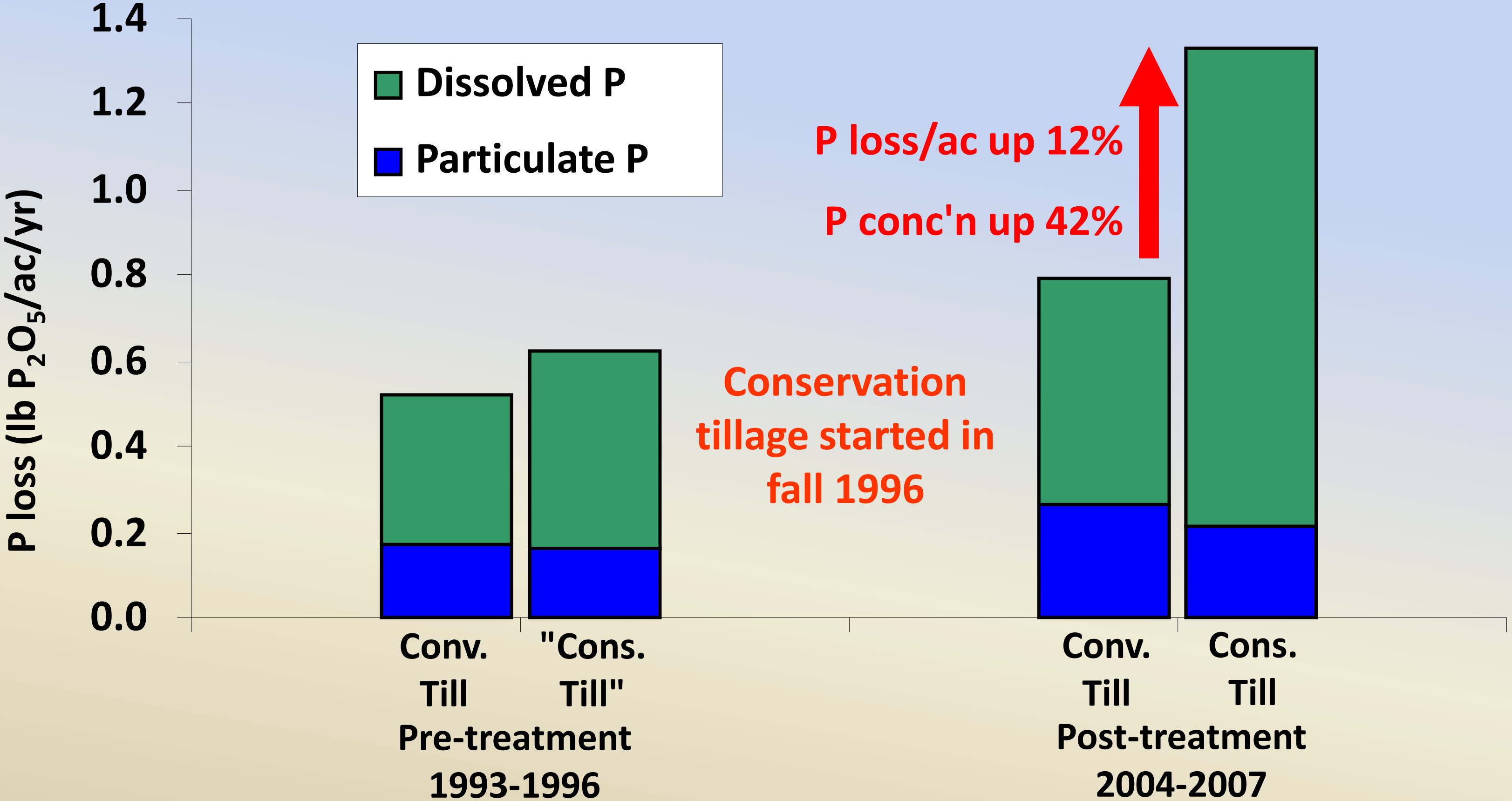




Effects of conservation tillage on water quality in South Tobacco Creek watershed:

- ✔ decreased total nitrogen export by 68%
- ✔ decreased sediment export by 65%
- ✘ but P was a different story ...

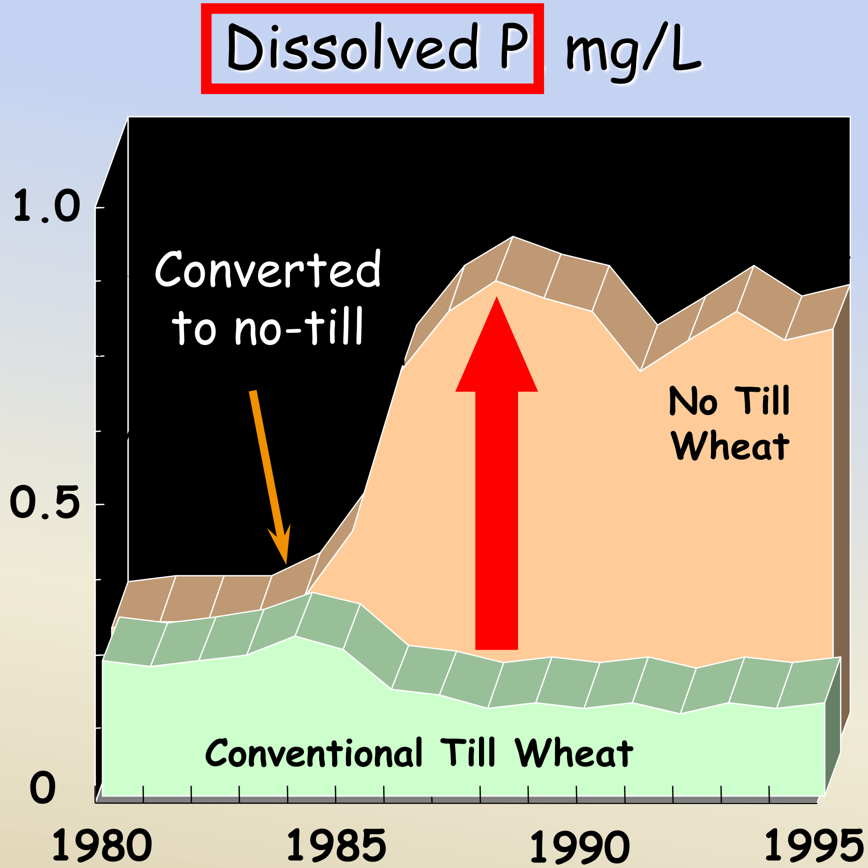
South Tobacco Creek twin watershed study: P loss from conservation tillage was <u>greater</u> than from conventional tillage ... because erosion of soil particles was a minor contributor to P loss in both systems

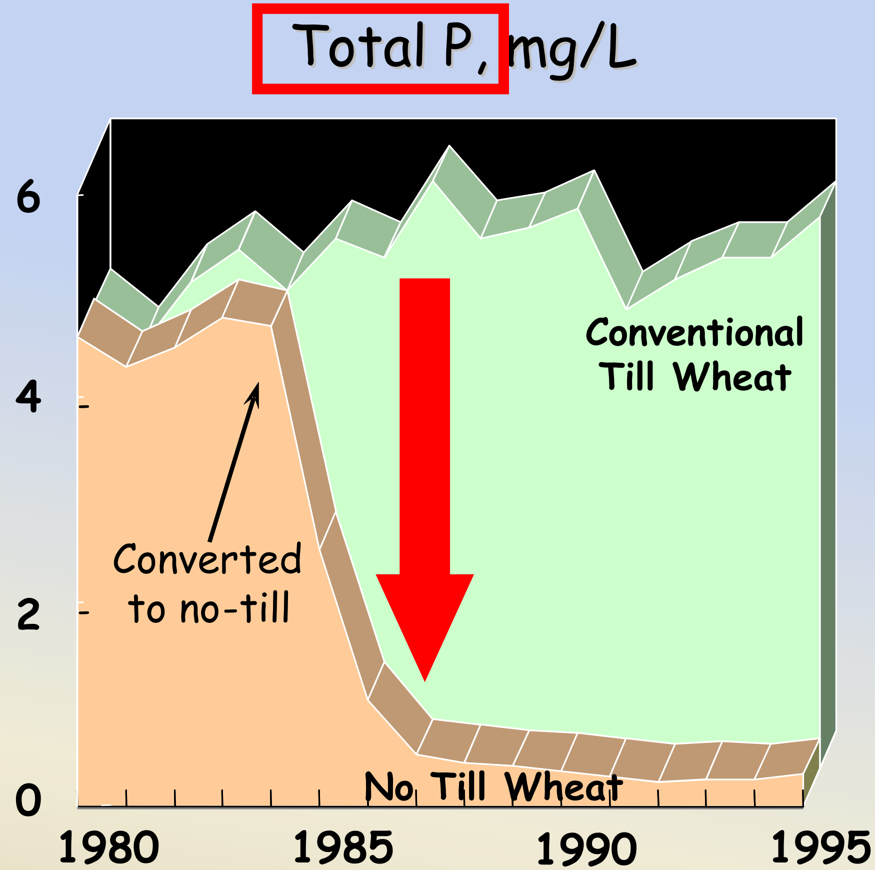


(Tiessen et al. JEQ 2010)

UNIVERSITY OF MANITOBA

In Oklahoma, conservation tillage increased losses of dissolved P, but reduced total P loss from wheat by 95% ... where most of the P loss was by erosion





El Reno, OK - Sharpley and Smith, 1994

University of Manitoba

Published January 12, 2017

Journal of Environmental Quality

TECHNICAL REPORTS

SURFACE WATER QUALITY

Increased Soluble Phosphorus Loads to Lake Erie: Unintended Consequences of Conservation Practices?

Helen P. Jarvie,* Laura T. Johnson, Andrew N. Sharpley, Douglas R. Smith, David B. Baker, Tom W. Bruulsema, and Remegio Confesor

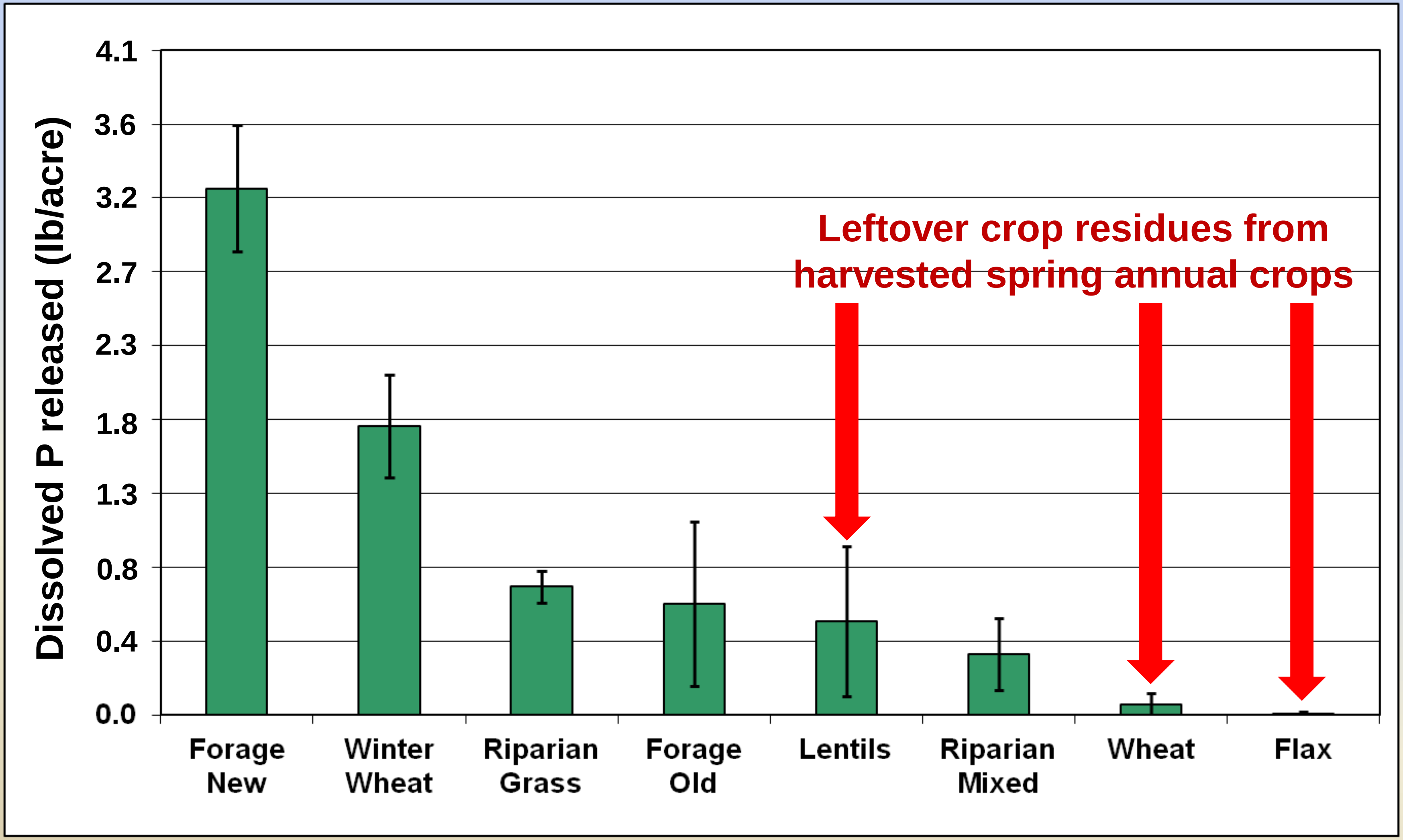
Abstract

Cumulative daily load time seri
marked a step-change increase
phosphorus (SRP) loads entering
from three major tributaries: the
Rivers. These elevated SRP loads
last 12 yr. Empirical regression r
the contributions from (i) incr
weather and precipitation pat
delivery (the combined effects o
and/or increased transport effici
fractions). Approximately 65% o
2002 was attributable to increa
runoff volumes accounting for t
SRP delivery occurred concomita
P budgets. However, within these
long-term, largescale changes i
tillage to minimize erosion and particulate P loss, and increased tile drainage to improve field operations and profitability. These practices can inadvertently increase labile P fractions at the soil surface and transmission of soluble P via subsurface drainage. Our

"Our findings suggest that changes in agricultural practices, including some conservation practices designed to reduce erosion and particulate P transport, may have had unintended, cumulative, and converging impacts contributing to the increased SRP loads, reaching a critical threshold around 2002."

Priority was established in response to growing challenges relating to phosphorus (P) enrichment, compounded by climate change, and aquatic invasive species (IJC, 2014); in February 2016, the governments of Canada and the United States announced new P

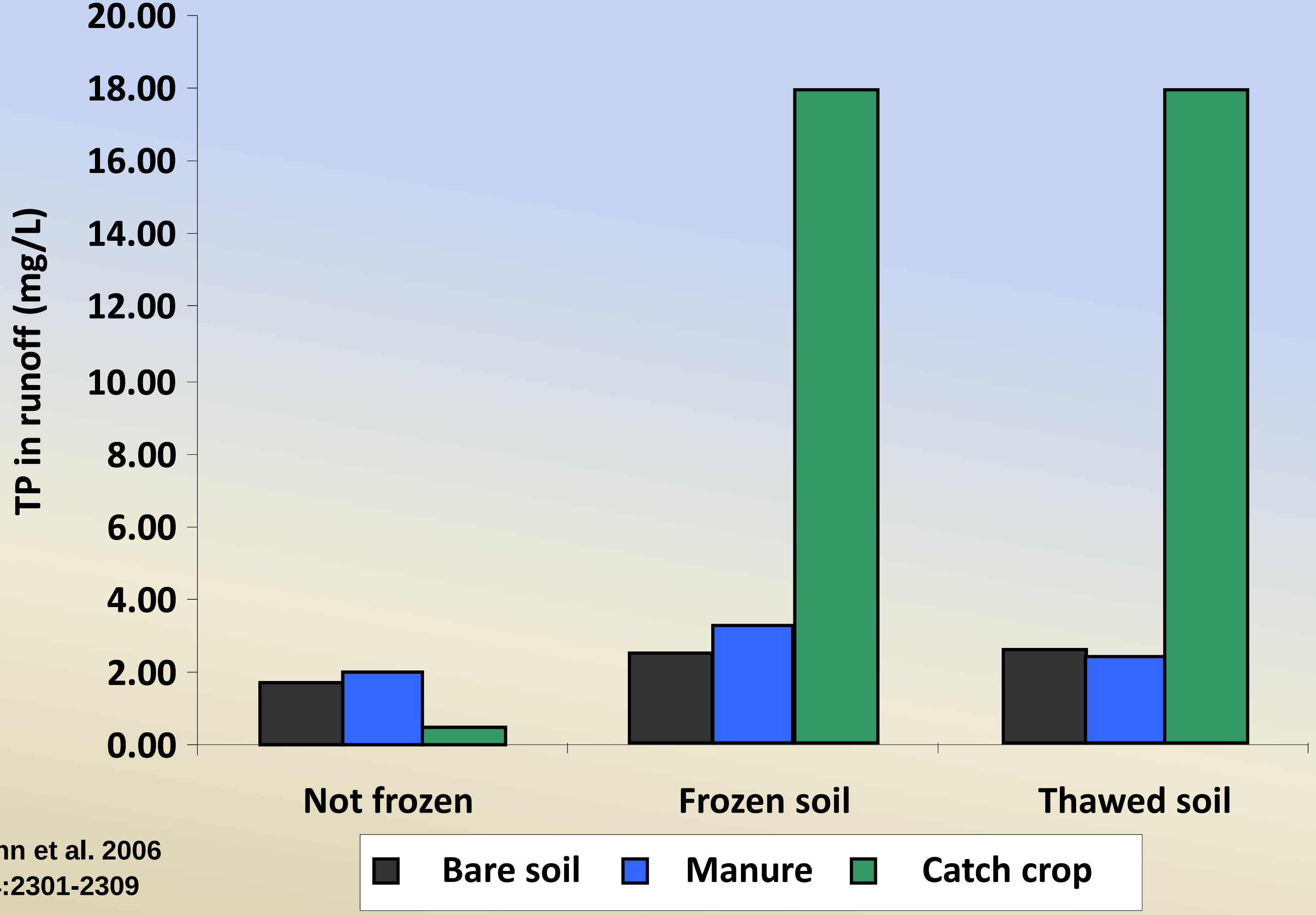
Fresh frozen green plant residues at greatest risk for simulated snowmelt runoff P losses



Elliott, J. 2013. Evaluating the potential contribution of vegetation as a nutrient source in snowmelt runoff. Can. J. Soil Sci. 93:435-443.

University of Manitoba

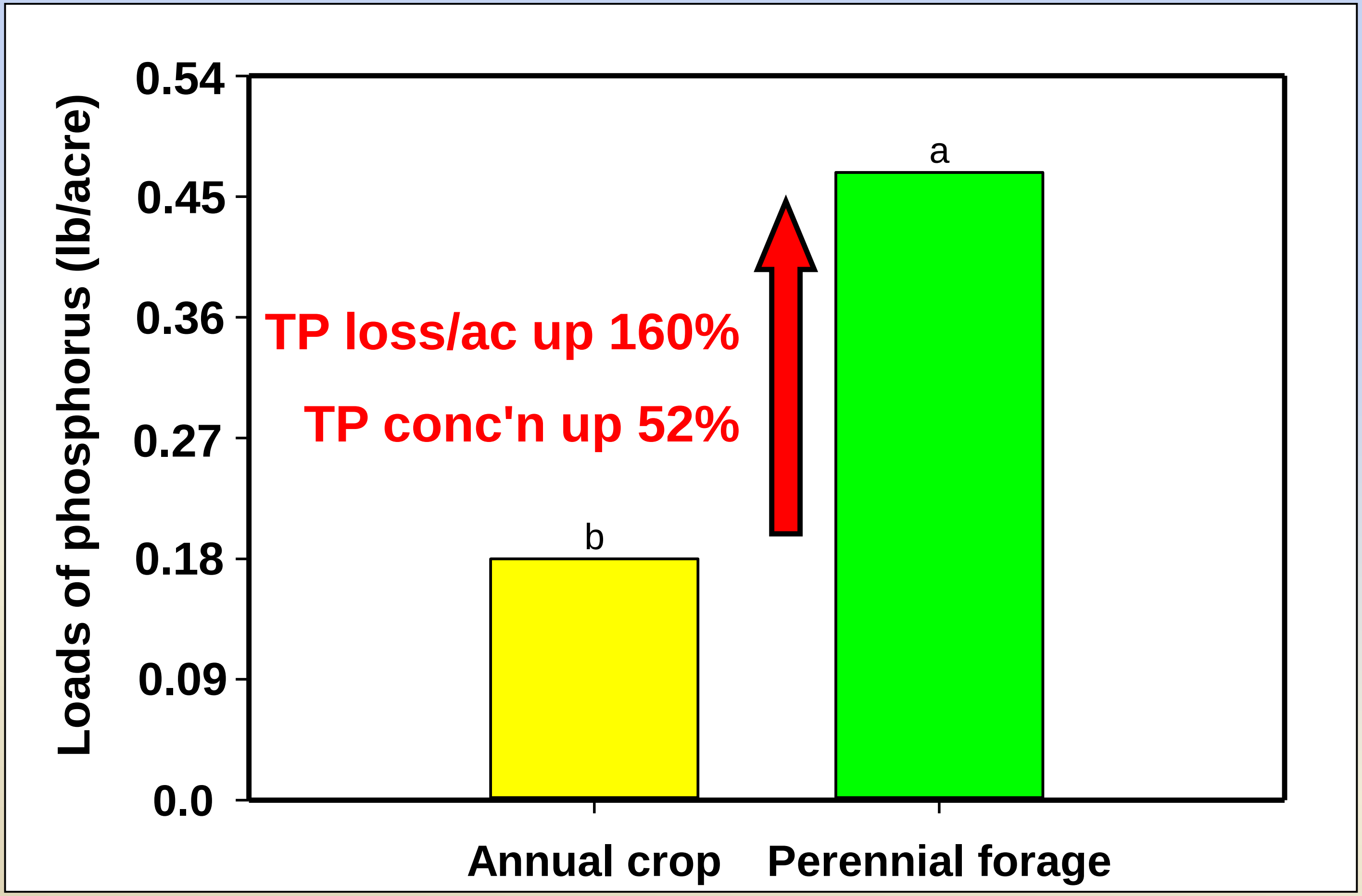
Freezing, thawing increases P loss from cover crops on manured soil: USDA rainfall simulation research in PA



Bechmann et al. 2006
JEQ 34:2301-2309

UNIVERSITY OF MANITOBA

Perennial alfalfa forage loses 2.6 x as much P in snowmelt runoff as conventionally tilled annual crops (8 site years)

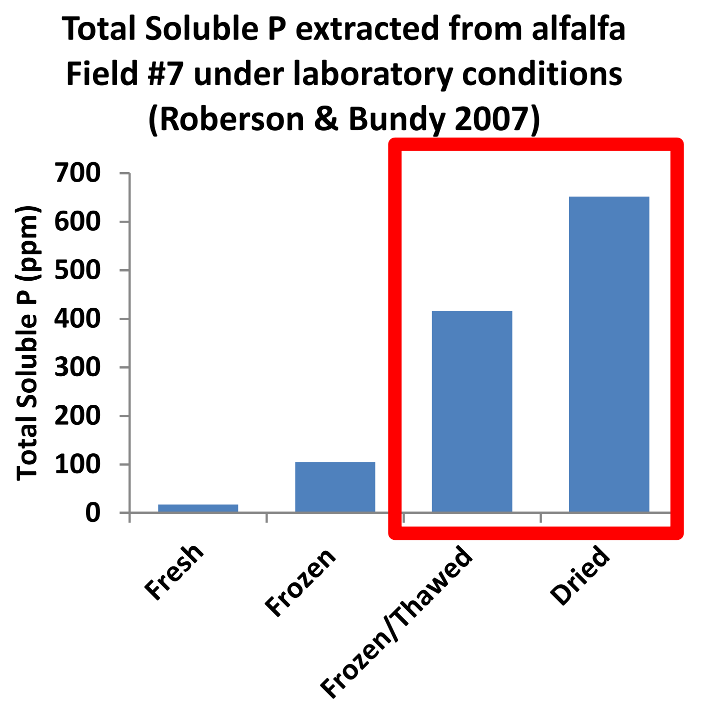


South Tobacco Creek Model Watershed – Liu et al. J. Environ. Qual. 43:1644–1655 (2014)

University of Manitoba

WI studies show that P losses from frozen or dried alfalfa under laboratory conditions did not match losses under field conditions

Lab Study



"Actual P losses likely depend on the timing and extent of plant freezing and drying and of precipitation events after freezing."

Field Study

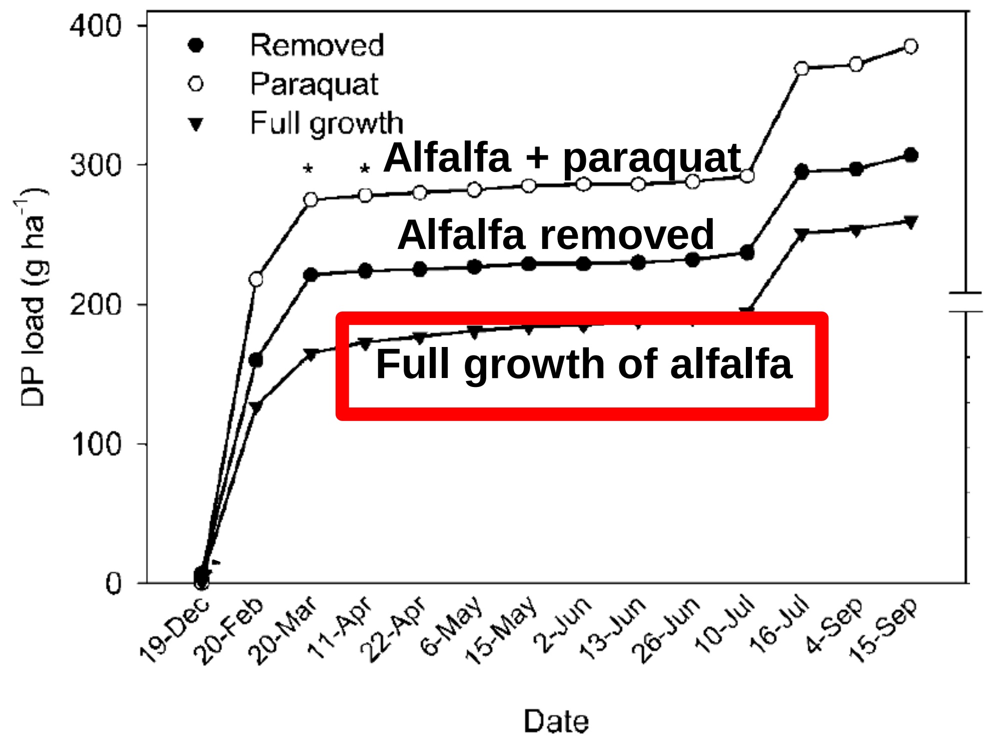


Fig. 4. Effect of fall cutting height and paraquat application to alfalfa (15 Oct. 2002) on cumulative dissolved reactive P (DP) (solid line) and natural runoff (dashed line) load at site 7, Oct. 2002 through Sept. 2003. (*) Orthogonal comparison of full growth and paraquat treatment on cumulative DP load was significant at the 0.20 probability level. **(Roberson and Bundy. JEQ 36:532–539 (2007))**

UNIVERSITY OF MANITOBA

Vegetated buffer strips in Manitoba not as effective as expected

Sheppard et al. CJSS 2006 (SE MB)

- VBS <u>reduced</u> runoff [TP] in 50% of cases,
- <u>increased</u> P in 18%, had <u>no effect</u> in 32%
- overall average … only 4% reduction in runoff [TP]

Sheppard et al. 2011 &

Habibiandehkordi et al. 2017

- No significant reduction in P with VBS in 45 of 54 seasonal measurements in Eastern-Interlake CD, Pembina Valley CD, and Little Sask. CD trials

UNIVERSITY OF MANITOBA

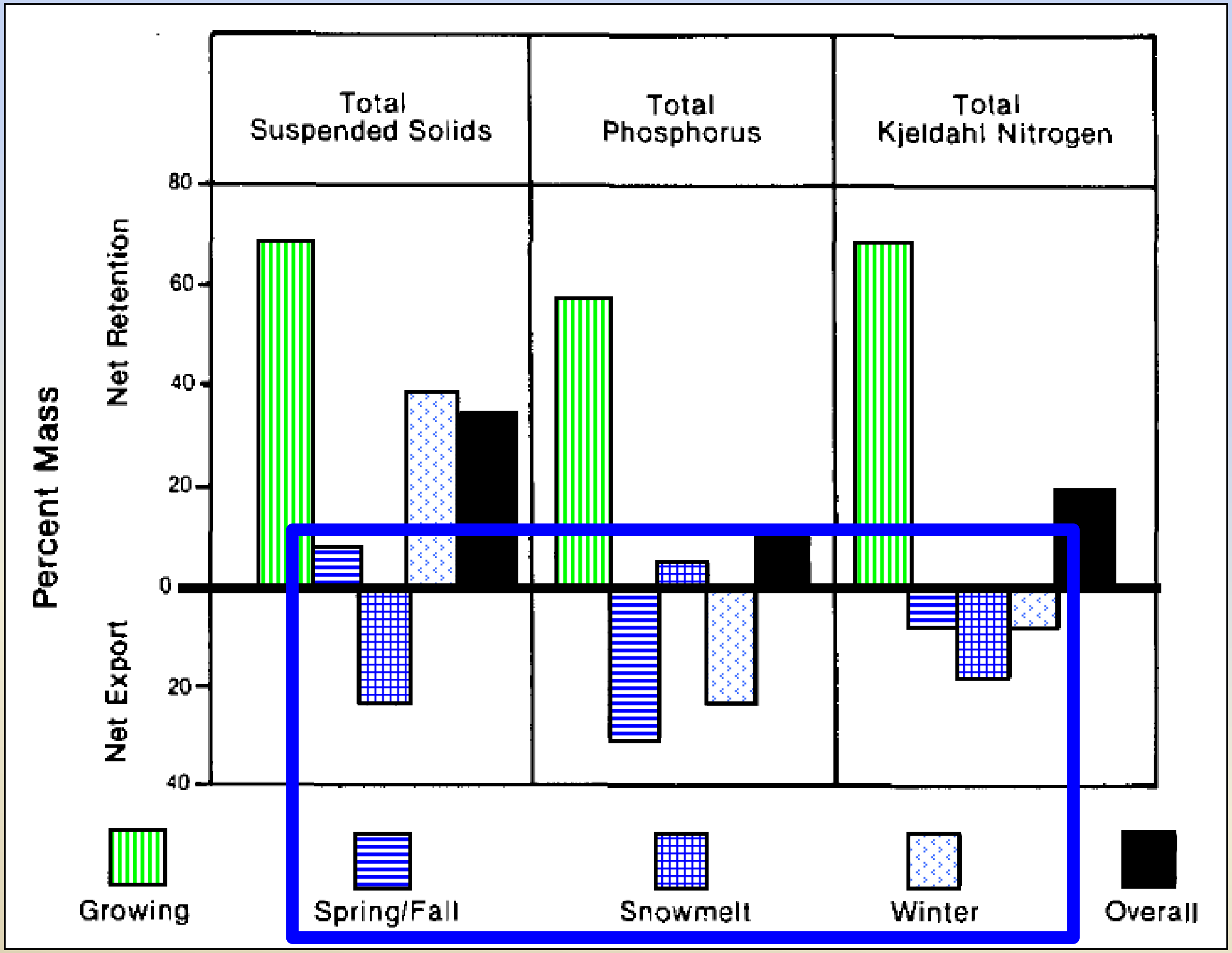
In-stream and near-stream processes (eg. vegetated buffers and biological uptake) are minimal during snowmelt

UNIVERSITY OF MANITOBA

Flow is often concentrated in only a small area of the buffer, overwhelming the nutrient retention system

University of Manitoba

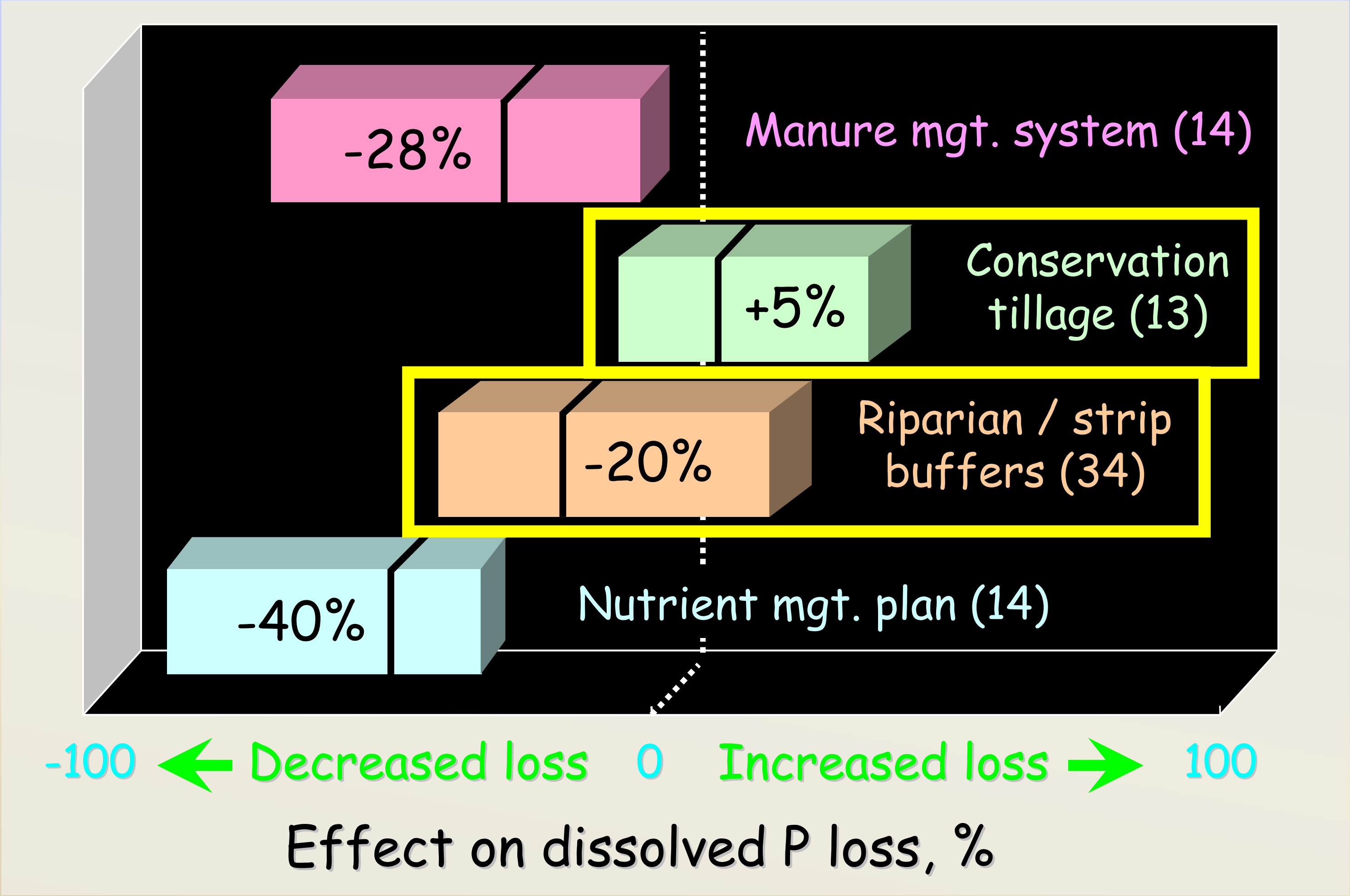
Barnyard vegetative filter strips: Ineffective outside growing season in Vermont



Schellinger & Clausen JEQ 1992

UNIVERSITY OF MANITOBA

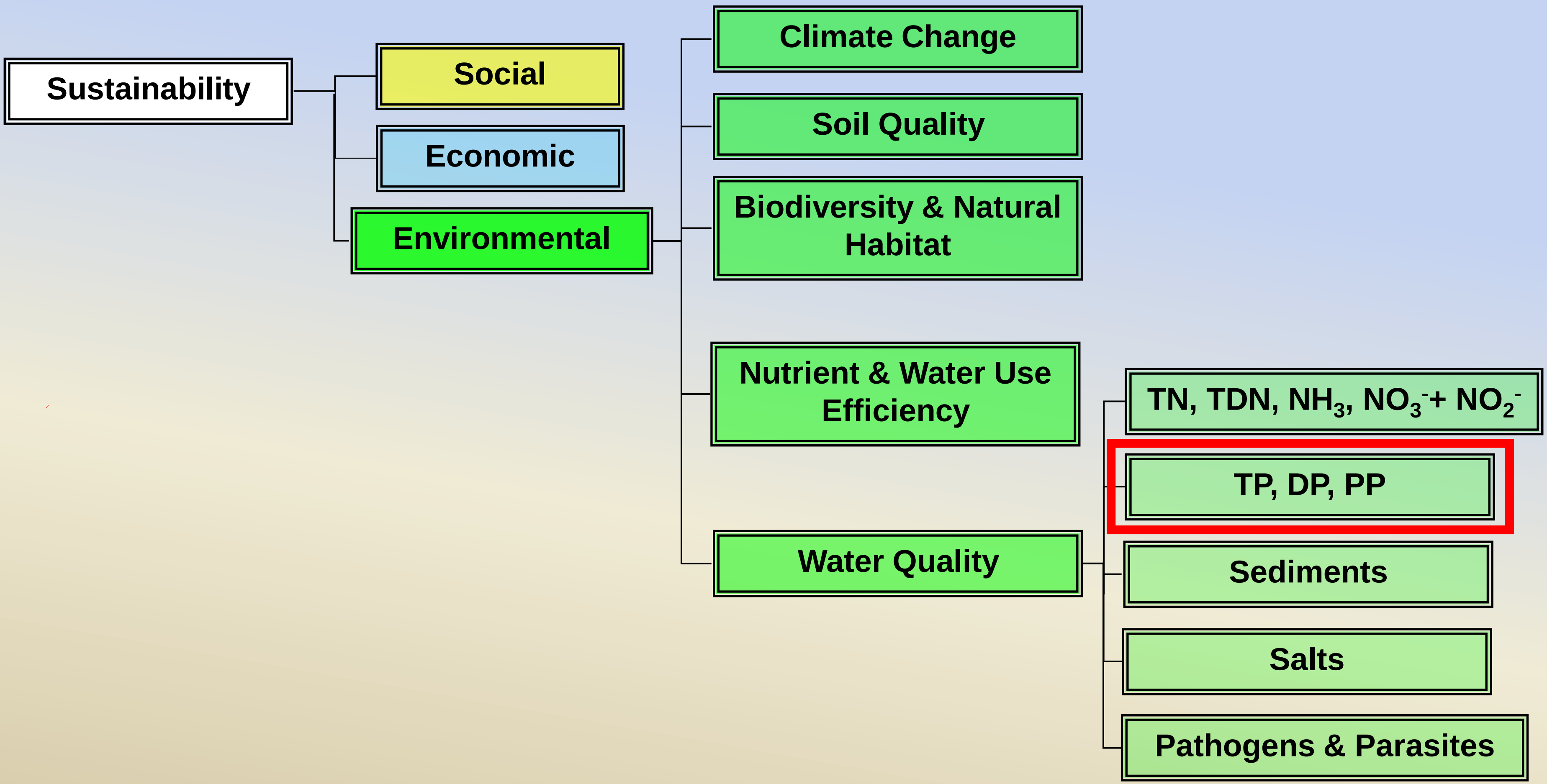
BMP effectiveness for reducing losses of dissolved P (Sharpley, adapted from Gitau et al. JSWC, 2005)



UNIVERSITY OF MANITOBA

Balancing Benefits, Co-Benefits, and Trade-Offs

- **Also, remember that P loss is only one of many objectives that agricultural practices must address to be sustainable**



University of Manitoba

Balancing Benefits, Co-Benefits, and Trade-Offs

- **No BMP, including conservation tillage, perennial forage or vegetated buffers is a cure-all, for all environmental issues and situations**

- **BMPs have different effects on different issues (eg. N vs P) in different environments (eg. rainfall on sloping land vs. snowmelt runoff on plains)**
- **Co-benefits are variable, but trade-offs are inevitable … let's use knowledge to maximize co-benefits & minimize trade-offs**

UNIVERSITY OF MANITOBA

Balancing Benefits, Co-Benefits, and Trade-Offs

- **Perhaps it's time to treat <u>environmental</u> health like <u>human</u> health ... with more effort to aim for improved overall health:**

  - **Diagnose the correct <u>cause</u>**
    - **assess each case individually and comprehensively**
    - **identify the real cause of the most important problem(s)**
  - **Prescribe the right <u>cure</u>**
    - **make sure the "cure" works**
    - **treat with precision**
    - **consider all the benefits**
    - **consider all the "side effects"**
    - **continuously monitor, adapt & fine tune the treatment**

University of Manitoba

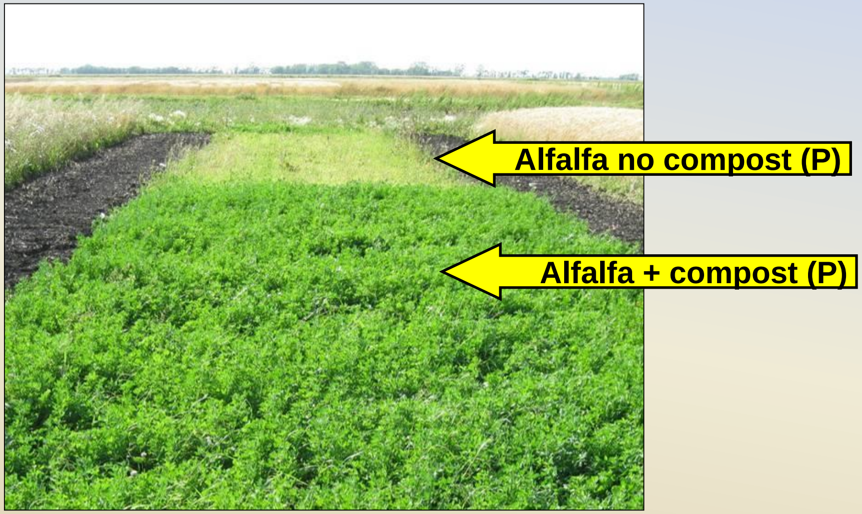
Overall Summary and Conclusions

1. **Starter P improves early season growth, advances maturity, and increases yield in corn, but has little benefit for soybean.**

   However, we need to add enough P to balance removal to maintain long term productivity for the whole crop rotation.

MAP 27 lb P_2O_5/ac

No P Check



UNIVERSITY OF MANITOBA

Overall Summary and Conclusions, cont'd.

2. Careful management of P rate, placement & timing is critical for reducing the risk of P loss to surface water ...

   especially considering that very small concentrations of P cause big problems with water quality ...

   and some traditional soil and water conservation practices that reduce water erosion may increase the loss of dissolved P in Northern Great Plains watersheds

University of Manitoba

Overall Summary and Conclusions, cont'd.

3. **We should be make sure that "beneficial management practices" are truly beneficial under local conditions ...**

   and aim for improving overall environmental health, being careful to consider all the co-benefits and trade-offs of beneficial management practices

UNIVERSITY OF MANITOBA

Acknowledgements

- M. Rogalsky, G. Bardella, & J. Heard
- D. Lange, Y. Lawley, C. Grant, & R. Mohr
- David Lobb, Kui Liu, Kevin Tiessen, Sheng Li
- Jim Yarotski, Larry Braul, Erin Zoski, Gao Chen (AAFC)
- Jane Elliott, Nancy Glozier (Environment Canada)
- Kelvin Hildebrandt, Don Cruikshank, Bill Turner, Dale Steppler (Deerwood Soil & Water Mgmt Ass'n)
- Steve Sheppard (Ecomatters)
- B. Hellegards (Richardson Pioneer)
- C. Linde and C. Cavers (CMCD Ctr.)
- J. Kostuik (Parkland Crop Diversification Foundation)
- M. Svistovski (Agriculture and Agri-Food Canada)
- R. Burak & J. Pawluk (Prairies East Sustainable Ag Inst.)
- S. Chalmers (Westman Ag Diversification Organization)
- C. Autsema
- Manitoba Pulse and Soybean Growers Association
- Western Grains Research Foundation
- Canada-Manitoba Growing Forward 2 Program
- Agrium, Agvise Laboratories, BASF, Monsanto-Dekalb

UNIVERSITY OF MANITOBA

Thank You!

UNIVERSITY OF MANITOBA